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QUANTITATIVE RISK ASSESSMENT: A TEST CASE

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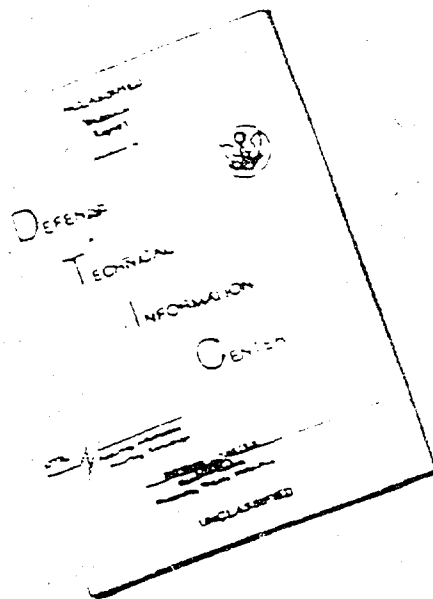March 1974

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Since the requirement for formal risk management in all major development programs, several methodologies have been suggested but few have been implemented with persistence. The Air Force Academy Risk Analysis Study Team suggested that a quantitative risk assessment technique based on network simulation and subjective probability estimates could be used to assess risk in the three primary development variables: cost, schedule, and technical performance. This thesis attempted to determine the feasibility and practicality of applying such a methodology to the A-10 Full Scale Development

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Program for cost and schedule variables only.

Significant problems were encountered networking the project and obtaining accurate, unbiased estimates. It was concluded that a low cost, external application of the methodology on a scale detailed enough to afford realism is impractical and duplicative. In addition, the authors questioned the applicability of formal risk assessment as a program control technique and the universal requirement for major DOD development projects to devise and maintain a formal risk analysis program.

In an effort to provide the Systems Program Office with better cost and schedule variance forecasts, simple regression models were developed. These techniques could possibly be used in program control to supplement contractor variance forecasts.
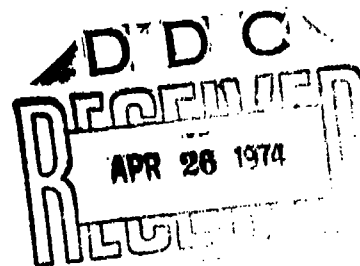
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THESIS

GSA/SM/74-1

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A TEST CASE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Graduate Systems Analysis

March 1974

PREFACE

This thesis is the result of a 5 month research that examined the application of a formal risk assessment methodology suggested by the Air Force Academy Risk Analysis Study Team. The intent was to determine the feasibility and practicality of applying such a methodology in an actual weapons system acquisition program environment. We hope that this paper will provide the reader with some insight into the difficulties of applying this risk assessment methodology to a real world situation and perhaps suggest more appropriate use of risk assessment in future research and development programs.

We would like to thank the members of the Directorate of Program Control in the A-10 Program Office, principally Captain Bob Cote, and Mr. H. Stein of Fairchild Republic Company for their cooperation and assistance in this effort.

As always, the views and conclusions are solely our own and we assume full personal responsibility for errors and omissions.

<div align="right">Stephen L. Amdor and Roy R. Kilgore</div>

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I.   Introduction

This thesis attempts to test the feasibility of a formal risk assessment methodology in an actual weapons acquisition program environment. The methodology essentially consists of obtaining subjective data in a probabilistic format and analyzing it via a rather sophisticated network simulation computer program. If successful, we anticipated that the methodology might well serve as a normative base for risk assessment in future weapons acquisition efforts. If unsuccessful, it should at least provide suggestions for alternative approaches to forecasting contractors' performance. A significant personal benefit was the invaluable practical exposure afforded the writers while still in the academic environment.

Motivation

Basic incentive for the study arose from efforts to improve Department of Defense (DOD) performance in the weapons acquisition process. During the past decade and with few exceptions thus far into this one, there have been notorious examples of cost overrun, schedule slippage and performance degradation within major weapons system acquisition efforts. Among the more recent and widely publicized are the USN/Grumman F-14 fleet defense interceptor, the USAF/Lockheed C-5A heavy logistic aircraft, and the USA/General Motors main battle tank.

A plethora of management approaches, contractual schemes, and accounting methods has failed to provide the desired results. Problems persist, as attested to by the current difficulties in the Rockwell International B-1 advanced manned bomber program (51:18). But there are successes, like the AC-130 gunship program (15).   Such successes

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lend credence to the assertion that at least some parts of current

DOD acquisition policy are producing positive results. Among those

aspects which are seen to be of potential benefit is an increased aware-

ness of the need for a way to assess program risk early in the cycle,

and to continue that assessment as long as significant uncertainty

remains. The question then arises, "How do we go about assessing

program risk?"

Toward the end of improving the weapons acquisition process, former

Deputy Secretary of Defense David Packard issued two memoranda on the

subject to the Service Secretaries. In those, Secretary Packard directed

the Secretaries to identify areas of high technical risk, to accomplish

"formal risk analysis" and to expand program management practices to

include explicit consideration of risk assessment, risk reduction, and

risk avoidance (19:1). In addition, Department of Defense Directive

(DODD) 5000.1 also contains reference to risk, requiring that the

Development Concept Paper (DCP) define program issues, including risk,

and that technical uncertainty be continually assessed (21). Also,

Air Force Systems Command (AFSC) Pamphlet 800-3 addresses risk analysis

in conjunction with the Defense Systems Acquisition and Review (DSARC)

process (3).

In response to these general guidelines, the Aeronautical Systems

Division (ASD) of Air Force Systems Command commissioned a study by

members of the faculty of the United States Air Force Academy (USAFA)

on risk analysis (33). We feel that the USAFA study is the collative

document on risk analysis within DOD. One of the observations in that

report serves as pointed motivation for this thesis:

> The technique which offers the most promise in quantitative
> risk assessment is a versatile, simulated network approach using

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group assessment techniques, subjective probability, technological forcasting, cost estimating, and other sources of input (33:73).

Further,

Conclusion: To our knowledge no major DOD program has developed or used a risk analysis of the magnitude envisioned in this report.

Recommendation: Initiate test cases immediately. Formal risk assessment and analysis should be used throughout these pilot programs to determine their feasibility and utility to a decision maker (33:9).

Background

Subsequent to the publication of that study at least one attempt has been made to test the feasibility of a simulated network approach to risk assessment. Bevelhymer wrote a thesis based on his efforts to test such an approach using the AGM-86A (SCAD) program as a test case (10).

The principal difference between Bevelhymer's work and that proposed in this thesis lies in the acquisition and treatment of data. Bevelhymer noted, as we do, that the preponderance of risk analysis literature suggests the use of subjectively obtained data, but his questions concerning how the "experts" should be chosen and how they should be questioned led him to initially attempt the simulation with data drawn from existing contract data documents (10:26).

Allowing the major data premise in risk analysis, that is, that cost, time and performance parameters are realizations of random variables, one must obtain a range of estimates for each parameter considered. Bevelhymer could not get such information solely from contractor supplied data items, which are deterministic in nature. He therefore was forced to resort to subjective estimates for range endpoints used to normalize the contractor supplied cost observations (10:37).

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We felt that this compromise, for the sake of methodological cost reduction, was questionable, especially in light of the fact that cost endpoints were ultimately supplied by an independent firm under contract to the SCAD System Program Office (SPO) to assist in systems integration and technological assessment. That was an atypical situation certainly not without real cost (10:37). Further, Bevelhymer had great difficulty with time estimates because no contract data elements explicitly provided any time estimate, much less ranges of estimates. Since he could not use contract time data items, he was forced to search elsewhere and eventually obtained subjective estimates from the Projects Division within the SCAD SPO (10:37).

We therefore chose to attempt a subjective assessment approach to data acquisition. Initially, we intended to use both the SPO and contractor personnel in two separate iterations to afford a comparative base. The SPO effort proved unfeasible simply because the detailed level of expertise did not exist there. Consequently we attempted to use "experts" from among the contractor's personnel, an intuitively optimum choice if one either assumes lack of bias or corrects for its presence. We attempted to do the latter, as described in Chapter 4.

Although Bevelhymer's work is the only actual test case using network analysis that we found, others have advocated it used and even produced hypothetical examples. See, for instance, Williams (53 , Brandt (13), Hwang (31), and Moeller (37). While not a network based technique, Thomas has successfully employed an accumulative approach using subjective inputs and producing probabilistic estimates of total risk in bidder replies to a Request for Proposals (49).

Overview

This thesis is organized into seven chapters and associated appendices. Problem statement and background are in this chapter. Chapter Two discusses risk assessment syntax and the assumptions pertinent to the methodology. In Chapter Three a brief discussion of the current Department of Defense management system is presented, along with some of its shortcomings. The proposed methodology is presented in Chapter Four. In Chapter Five a comprehensive assessment of the failure of the methodology is given and the problem is restated in terms of the program manager's requirements. Chapter Six briefly discusses some secondary attempts at forecasting contractor performance using contract data elements and least squares analysis. Chapter Seven contains our conclusions and recommendations for further study.

Problem Summary

To recapitulate, this thesis attempts to test the feasibility of a formal risk assessment methodology that uses subjectively based probabilistic estimates as inputs for a computerized network simulation. The prime criterion for judging the feasibility is whether or not the methodology provides useful information to the decision maker under reasonable constraints like: (a) is the information produced cogent, (b) is it accurate, and (c) is it timely.

II. Syntax and Assumptions

This chapter establishes a risk assessment syntax, explains
pertinent concepts, and lists assumptions used in the study.

Uncertainty

Among the adjectives that might be used to describe the weapons
system acquisition environment is one that seems particularly appropriate:
uncertain. The implication of "uncertainty" ranges from lack of absolute
sureness, to lack of conviction, to no opinion, to confusion, and so
forth. We again draw upon the USAFA study on risk analysis for syntac-
tical convention:

Uncertainty: Incomplete knowledge (33:8).

Further, most works on risk analysis are primarily directed toward
recognition and assessment of technical uncertainties (13, 3, 32).
The USAFA study categorizes uncertainty in the weapons system acquisition
process in four interrelated areas.

Target uncertainty is the uncertainty associated with defining
a need or required operational capability (ROC) and reducing that need
to cost, schedule, and performance goals (33:23-25). Principal among
the factors contributing to target uncertainty are: (a) validity of the
need, (b) confusion resulting from the formal requirements generation
process, (c) questions concerned with the physical and performance
characteristics required to meet the need, and (d) inherent innaccuracies
associated with time and cost estimating techniques. Target uncertainty
stems from the lack of answers to the question "What do we need?"

Technical uncertainty is closely related to target uncertainty,
the essential difference being that technical uncertainty addresses
the question " Can it be done at all, for any price?" (33:25-28).

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The distinction between uncertainty of the criteria used in solving the problem and the technical solution itself must be made. The answers to "Does the technical solution lie beyond program time and cost constraints?" and to "Is the solution beyond present technological capabilities?" impinge upon the degree of technological uncertainty. Unanticipated technological problems add even more uncertainty to the estimation process. These technological problems have been prevalent in recent years, largely due to the "doctrine of quality" philosophy among U.S. weapons designers. This philosophy prefers advanced technology often at the expense of quantity (20:1). This attitude has only recently been subjected to question and the test case for this study, the Fairchild Republic A-10 specialized close air support aircraft, is one result. The phrase applied to this approach is "design to cost" (1:22).

Internal program uncertainty is associated with selecting a particular management approach to the problem and then carrying it out. (33:28-30). The results of a particular management style or philosophy are impacted by uncertainties related to estimates in the target and technical areas, by the particular acquisition strategy selected, and are impacted by arguments among Congress, force structure planners, threat assessors, and users. These vascillations among interested agencies are part of the final category of uncertainty, process uncertainty.

Process uncertainty pervades the other three categories, as mentioned above. The process uncertainties derive from influences external to the program itself (33:30-33). In addition to those areas listed as affecting internal program uncertainty, the process area includes interservice rivalry, national policy, budgetary considerations, and Congressional "pork barrel" activity. Obviously, this area is the one

the program manager has the least control over. Process uncertainty

may prevail over all attempts at assessing and controlling the other

three types.

Formal Risk Analysis

Lack of explicit direction on how to accomplish a "risk analysis"

has led to several approaches, some qualitative, the B-1 bomber program

for instance (39), and some quantitative, such as Thomas' method (49).

For the purposes of this study we consider "formal" to mean a separate

and documented effort, conducted in accordance with normally accepted

scientific investigative criteria. From the USAFA study come other

pertinent definitions:

> Risk: The probability that a planned event will not be attained
> within constraints (cost, schedule, performance) by following a
> specified course of action. [note that risk is the complement of
> the cumulative probability, i.e., $R=1-Pr(X$ less than or equal to $x)$].

> Risk assessment: A comprehensive and structured process for estimating
> the risk associated with a particular alternative course of action;
> also the product of such a process.

> Risk management: The generation of alternative courses of action
> for reducing risk. [Sometimes called risk avoidance].

> Risk analysis: The process of combining risk assessment with risk
> management in an iterative cycle; also the produce of such a process
> (33).

Parameters

As noted previously, three parameters, or three classes of para-

meters, are used to quantify these uncertainties. They are cost, time

and performance. By cost, we mean dollar costs for obtaining the hard-

ware, software, and services necessary to fulfill the contractual

obligations. Time and scope limitations on this thesis preclude

addressing such things as opportunity costs, depreciation, and the very

real costs attributable to federa. administration of the program.

However, increased emphasis is being placed on those excluded costs and there is certainly room for further study (see Ref. 2).

The time parameter is calendar time from contract award and is associated with periods between significant contractual milestones, e.g., rollout, first flight, etc. Certain government specified milestones also become significant but are not necessarily hardware oriented. The Defense System Acquisition and Review Council meetings are examples (3).

The performance parameter is the most ill-defined and perplexing. The many factors that could be used in any one program depend on the weapons, the threat, the mission, and, not insignificantly, each other. Performance parameters are not homogeneous and hence don't readily lend themselves to an additive scheme like network simulation. For example, the Development Concept Paper for the A-10 (18) specified such general performance requirements as high payload capacity, small turn radius, and long loiter time. As yet, there are no transformations that allow additive accumulation of some performance parameter that simultaneously represents ordnance capacity, radial acceleration, and time-on-target achievement levels.

Assumptions

As noted earlier, these parameters must be considered as random variables if a probabilistic estimate of program success (in one or more of the parameters) is to be produced. This condition leads to the first of several assumptions used in this thesis, namely that subjectively estimated distributions of each parameter are marginal distributions (27). This assumption does not necessarily imply independence among the parameters. Peck and Scherer point out that observations by program managers tend to support the hypothesis that there is indeed some

dependence, although it has not been proven empirically (40). If

independence is not so, the conclusion must be that there exists some

trivariate distribution for each case, although its form is unknown.

That is, there is some unknown relationship among the three variables

that, were it known, would allow the manager to make tradeoffs among

the three under a specified total risk constraint, R, where R lies

in the range 0 to 1.0.

Further, we chose to disregard the performance aspect of the risk

assessment and to concentrate on only the time and cost parameters.

Three considerations affect this assumption. First, as noted earlier,

the performance parameter is not homogeneous and hence is not tractable

in a network simulation. Second, the nature of this particular test

case, the A-10 specialized close air support aircraft, reduces the

potential impact of not considering the performance variable. The

A-10 is a low state-of-the-art venture not requiring significant

technical advances. Further technical risk reduction came from the

Competitive Prototype Phase (CPP) wherein two prototypes were built

and tested in an operational setting. For further information on the A-10

program, see Appendix A. Thirdly, time available for the study precluded

attempting all three. We acknowledge the questionability of this

assumption in most cases since virtually all of the literature and

most of the operators we have interviewed look upon risk analysis

as technical risk analysis (53).

A third major assumption was that we would be able to construct

a valid summary network, with well defined activities or groups of

activities, based on the Work Breakdown Structure (WBS). The WBS is

an integral part of the DOD management system and will be explained in

some detail in Chapter 3. For now, the definition take from Military

Standard 881 will suffice:

> Work breakdown structure (WBS). A work breakdown structure is a
> product-oriented family tree composed of hardware, software, serv-
> ices, and other work tasks which result from project engineering
> efforts during the development and production of a defense materiel
> item, and which completely defines the project/program. A WBS
> displays and defines the product(s) to be developed or produced
> and relates the elements to be accomplished to each other and to
> the end product (35:2).

A fourth assumption was that among the contractor personnel we could

find experts who could give us time and cost estimates, in the form of

most likely, minimum, and maximum points, for each activity in the WBS

derived network. As a corollary, we assumed that the estimates so rend-

ered would be sufficiently accurate and unbiased as to afford a measure

of reliablility in the ultimate answer. This assumption, when constrained

by the summary network criterion mentioned in assumption three, proved

to be incorrect.

The fifth assumption was that we need not concern ourselves with

the entire program but could limit the study to the airframe alone,

including the gun and engine as unit activities only. The assumption

was ultimately altered by adverse developments in the study so that

we eventually restricted our attention to just a portion of the Fairchild

Republic Company (FRC) effort, namely the Basic Structure element. The

FRC task description of the Basic Structure element is:

> The design, development, fabrication, assembly, procurement of
> parts and materials, inspection, installation, and functional
> test/checkout of the structural, aerodynamic, subsystems components
> of the airframe, and the final assembly and functional checkout of
> the air vehicle. Includes the fuselage, nacelles, empennage, wing
> wing control surfaces, pylons, and assembly thereof (16:2-18).

For further information on the A-10 Full Scale Development program

the reader is again referred to Appendix A.

III.   The Current System

As a prerequisite to understanding the proposed methodology, one
must first be familiar with certain aspects of the Department of Defense
Resource Management System (RMS), namely a subsystem thereof called
Selected Acquisitions Information and Management System (SAIMS) (24:10).
This chapter presents a simplified review of pertinent aspects of SAIMS
and of the Work Breakdown Structure, which is the reporting foundation
for SAIMS. The reader familiar with SAIMS and WBS terms can safely skip
to the section on problems and shortcomings on Page 22.

SAIMS Review

As inferred above, SAIMS is but one of four subsystems (see Figure
3-1) of the DOD Resource Management system. SAIMS itself is further sub-
divided into three sections. These relationships are depicted in Figure
3-1.
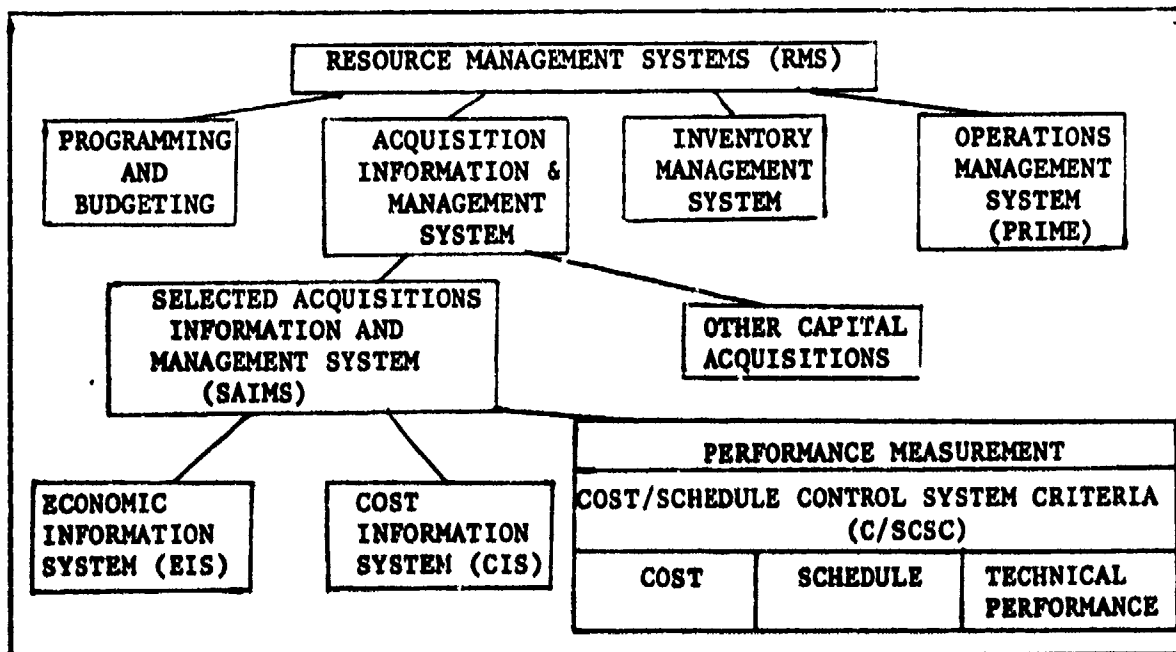
Figure 3-1 RMS - SAIMS Relationships

Performance Measurement. We are concerned with only one of the

three subsections of SAIMS, namely Performance Measurement. As a note

of caution, the word "performance" takes on two different meanings

throughout RMS literature and so might prove confusing. In the phrase

"performance measurement" it means an assessment of the contractor's

progress on all aspects of the contract. On the other hand, in "tech-

nical performance" it implies some measurement of hardware/software

capability, e.g., airspeed, payload, etc. It is also important to

realize at the outset that each report derived through SAIMS ultimately

comes from information taken from the contractor's data base and as such

constitutes a real cost to the government.

In any attempt to assess the effectiveness of a risk assessment

methodology designed to track performance to date and predict the

future behavior of the three contract variables, one must consider what

is presently being done to analyze and control those variables. The

Performance Measurement subsections of SAIMS delineates that effort.

There are three basic elements of the Performance Measurement subsystem,

only two of which are important here, the Cost/Schedule Control System

Criteria and the Cost Performance Report.

   The Cost/Schedule Control System Criteria (C/SCSC) are used to
   evaluate the effectiveness of the contractor's internal systems.
   The C/SCSC do not require any data to be reported to the Govern-
   ment, but do provide for access to data needed to evaluate the
   system and monitor its operation during the life of the contract.
   [The Air Force equivalent of C/SCSC is Cost/Schedule Planning and
   Control Specification, C/SPCS]

   The Cost Performance Report (CPR) is the vehicle which actually
   provides cost and schedule information to the DOD project office.
   The CPR is a monthly report of contractual progress with identi-
   fication of significant problems obtained through analyses of
   variances from plans (24:47).

   Work Breakdown Structure. To facilitate orderly aggregation of

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information under C/SCSC for the Cost Performance Report, the SAIMS

system uses the Work Breakdown Structure concept previously mentioned.

Repeating, a WBS is a product oriented family tree structure of all the

hardware, software, services and other tasks of the system to be devel-

oped, produced, supported, and/or operated. Depending on the user, there

are actually four types of Work Breakdown Structures. We are concerned

with a portion of the Contract Work Breakdown Structure. Those defini-

tions and others from Military Standard 881, "Work Breakdown Structures

for Defense Materiel Items" are listed here for information and clarity.

> Summary work breakdown structure (Summary WBS). A summary work
> breakdown structure consists of the upper three levels of a WBS
> prescribed by this standard and having uniform element terminology,
> definition, and placement in the family-tree structure. The upper
> three levels of a summary WBS have been organized within the follow-
> ing categories of defense materiel items:
>
> a. Aircraft system
> b. Electronics system
> c. Missile system
> d. Ordnance system
> e. Ship system
> f. Space system
> g. Surface vehicle system
>
> Level identification. The three levels specified are defined as
> follows:
>
> Level 1. Level 1 is the entire defense materiel item; for
> example, the Minute-man ICBM System, the LHA Ship System, or the
> SM-138 Self-Propelled Howitzer System. Level 1 is usually directly
> identified in the DOD programming/budget system either as an integral
> program element or as a project within an aggregated program element.
>
> Level 2. Level 2 elements are major elements of the defense
> materiel item; for example, a ship, an air vehicle, a tracked
> vehicle, or aggregations of services, data, and activities; for
> example, systems test and evaluation.
>
> Level 3. Level 3 elements are elements subordinate to level
> 2 major elements; for example, an electric plant, an airframe, the
> power package/drive train, or type of service; for example, techni-
> cal evaluation. [Below level 3, the contractor identifies the levels]

Project summary work breakdown structure (Project summary WBS). A project summary work breakdown structure is a summary WBS tailored to a specific defense materiel item by selecting applicable elements from one or more summary WBS(s) or by adding equivalent elements unique to the project.

Contract work breakdown structure (Contract WBS). Contract work breakdown structure is defined as the complete WBS for a contract developed by a contractor in accordance with this standard and the contract work statement. The contract WBS comprises the selected project summary WBS elements included in the contract and those extensions by the contractor which cover the lower levels of WBS.

Project work breakdown structure (project WBS). Project work breakdown structure is defined as the complete WBS for the project, containing all WBS elements related to the development and/or production of the defense materiel item. The project WBS evolves from the project summary WBS extended to include all contract WBS(s) and equivalent WBS(s) resulting from DOD in-house efforts.

Work breakdown structure element. A work breakdown structure element is a discrete portion of a work breakdown structure. WBS elements may be either an identifiable product, set of data, or a service. (35:2-3).

As noted, we were ultimately concerned in this study with a specific element of a Contract WBS, namely a level 4 element called Basic Structure from the Fairchild Republic Company (FRC) Contract WBS for the A-10 Full Scale Development Program (commonly called the DT&E phase, for Development, Test and Evaluation). The pertinent portion of the FRC Contract WBS is reproduced in Figure 3-2 as an aid to understanding the WBS.

Figure 3-2 Basic Structure WBS

Work Packages. Each level 6 WBS element (in this case) is further subdivided into a set of work packages. A work package is a short span discrete task identified by the contractor as part of the WBS element. The work package is the fundamental building block of the WBS and is also the basic control point for managing and accounting. A work package has the following characteristics: (a) it is a unit of work at the working level, (b) it is unique, (c) it is assigned to a single operating organization, (d) it has scheduled start and completion milestones, (e) it has a budget in dollars, hours or other units, (f) it is of small size and short duration to minimize effort involved with assessing work-in-process levels, (g) it is integrable both with its cost account and with the appropriate WBS element, and (h) it has a specific method for planning and measuring performance (17:34).

There are three types of work packages used in the FRC Management Control and Information System. The unfamiliar reader would do well to remember them and the methods which each uses to measure performance because the subject arises again later in this chapter and in Chapter 4. A Discrete work package is one that has a specific, tangible and measurable result or output. A Level of Effort (LOE) work package contains work that can be planned and controlled by time phased budgets, i.e., work that cannot be identified into Discrete work packages. An Apportioned Effort work package contains work that is directly related to Discrete work packages of another cost account and is not readily divisible into short span work packages. The ratio (%) of the Apportioned Effort to its related Discrete work package must be specified. (17:33)

Cost Accounts. Sets of like work packages conforming to a part of a WBS Control Level Element (CLE, e.g., the 6 level element 1.1.2.1.9

FUSELAGE INTEGRATION AND ASSEMBLY shown in Figure 3-2) are functionally
grouped into tasks of work directly assignable to specific program
functional organizations like Design, Tool Planning, Lofting, etc. These
assignments produce Cost Accounts. Cost accounts identify every program
functional organization with work to do on a Control Level Element, and
therefore a discrete set of (cross functional) cost accounts will sum to
a single WBS/CLE. Types of cost accounts conform to the types or work
packages that make them up, i.e., Discrete, LOE, and Apportioned Effort.
With the exception of allowing 10% LOE work packages in a Discrete cost
account, the makeup is homogeneous. That is, there cannot be a mix of
types of work packages in a given type of cost account.

As cautioned earlier, the method of work package performance measure-
ment is important. Since openings and closings of work packages cannot
readily be made to conform to the monthly CPR reporting period, some
estimate of progress, for CPR purposes, must be made while the package
is open. In the case of FRC work packages performance can be measured
four ways: (a) standards like accepted time and motion tables, etc., (b)
50% start - 50% completion, (c) milestones, and (d) passage of time (for
LOE packages only). In the 50% start - 50% completion case a package
that is actually 99% complete at CPR accounting time will only be shown
to be 50% complete. Similarly, a package that has 100% of its "value"
assigned to a closing milestone may be quite close to completion yet show
no progess at all on that particular CPR. The assumption is, of course,
that the combination of short span and over-assignment of other work
packages will work to correct the mis-information on the next CPR. It
can be inferred from the above discussion that a similar thing occurs on
a more grand scale at the cost account level.

Figure 3-3 helps clarify the process. Again, a Control level
Element would be one of the 6 level elements listed on Figure 3-2. Let
WBS elements be numbered on Figure 3-3 and functional areas be lettered.
In cost account G5 on the diagram there are six work packages, two in each
of three task organizations in the G functional area. Horizontally G5
contributes to the sum making up CLE number 5. The aggregation process
continues upward for management information and to the left for CPR
information.

Analysis. To analyze the effectiveness of the contractor's efforts,
data is accumulated at the cost account level and summed through the WBS
structure to level 3, where they are reported in the CPR. The C/SCS
Criteria require that the contractor be able to provide the following
information:

   1. Budgeted Cost for Work Performed (BCWP). The sum of the budgets
   for completed work packages and completed portions of open work pack-
   ages, plus budgets for level of effort (LOE) and apportioned effort
   activity completed. [What you planned to spend for the work you
   actually accomplished - earned value, EV]

   2. Budgeted Cost for Work Scheduled (BCWS). The sum of the budgets
   for work packages scheduled to be accomplished (including in-process
   work packages), plus the amount of level of effort and apportioned
   effort scheduled to be accomplished within a given period of time.
   [What you plan to spend for the work you plan to accomplish - planned
   value, PV]

   3. Actual Cost of Work Performed (ACWP). The sum of actual costs
   for completed work packages and completed portions of open work
   packages, plus costs associated with level of effort (LOE) and
   apportioned effort activity completed. [Dollar value of resources
   consumed in the accomplishment of work performed-actual costs, AC]

   4. Budgeted Cost at Completion (BCC). The program budget.

   5. Estimated Cost to Completion (ETC). How much it will cost to
   complete the program.

   6. Estimated Cost at Completion (EAC). The sum of ACWP and ETC.

   7. Cost and Schedule Varainces with explanations.

   8. Traceability. How and where you got the information (24:50,
   4:121).

18
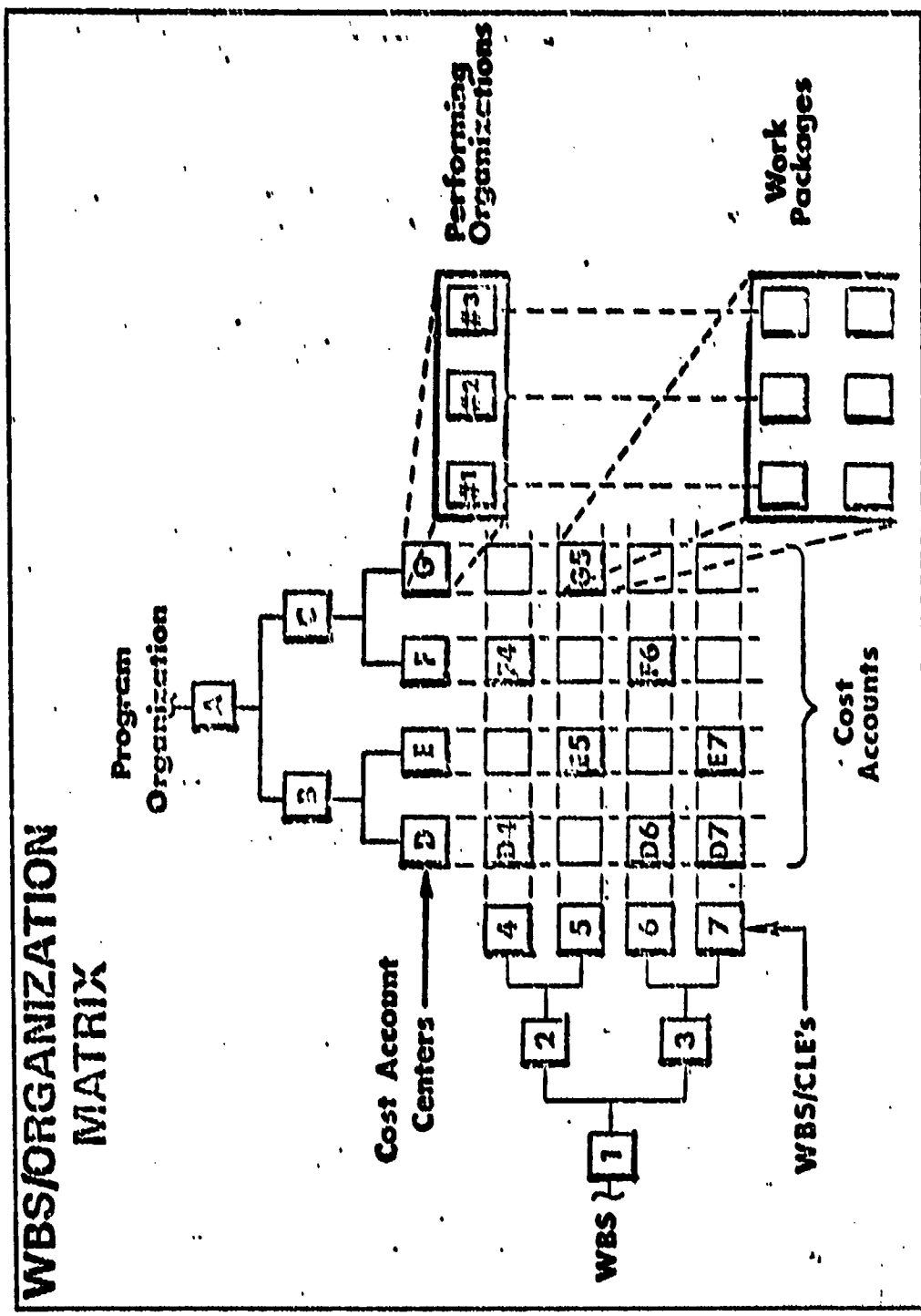
Figure 3-3 · WBS/Organizational Matrix

19

Items 1 through 7 are provided in the CPR. The format for the CPR is specified in the DOD Data Item Description DI-F- 6000A.

The concept of "earned value" or BCWP is important to the analysis. Without it, ambiguity arises. For instance if, in Figure 3-4, only the solid (actual cost) and long dashed (budget) lines were available one would not be sure whether the program was ahead of or behind schedule. The apparent cost and schedule variances are shown as "Cost Overrun ($)" and as "Ahead of Schedule" or "Behind Schedule" on the left side of the "time now" line. Does the actual cost point imply that the work scheduled has been accomplished sooner than expected for the budgeted cost or does it perhaps mean that the contractor has spent "Cost Overrun ($)" dollars too much to achieve the budgeted work, or is it a combination of the two? Addition of the short dashed line (earned value) clarifies the picture. The dollar value of work associated with the intersection of the short dashed line and the "time now" line has been "earned." The right side of the figure correctly depicts what has actually happened. By comparing earned value line to budget line or actual line, we can measure performance against actual achievement. It is clear that the schedule variance is adverse, that is, we have not accomplished what we planned to at the time we planned to do it. Cost variance is also seen to be worse than shown on the left. Further, by adding an Estimate to Completion (ETC) to the actual cost figure, we can arrive at an Estimate at Completion (EAC). From that we subtract planned value at completion and arrive at an estimated cost variance at completion. To summarize the procedure, we list these simple formulas:

1. Earned value - planned value = schedule variance (in dollars)

2. Earned value - actual cost = cost variance (also in dollars)

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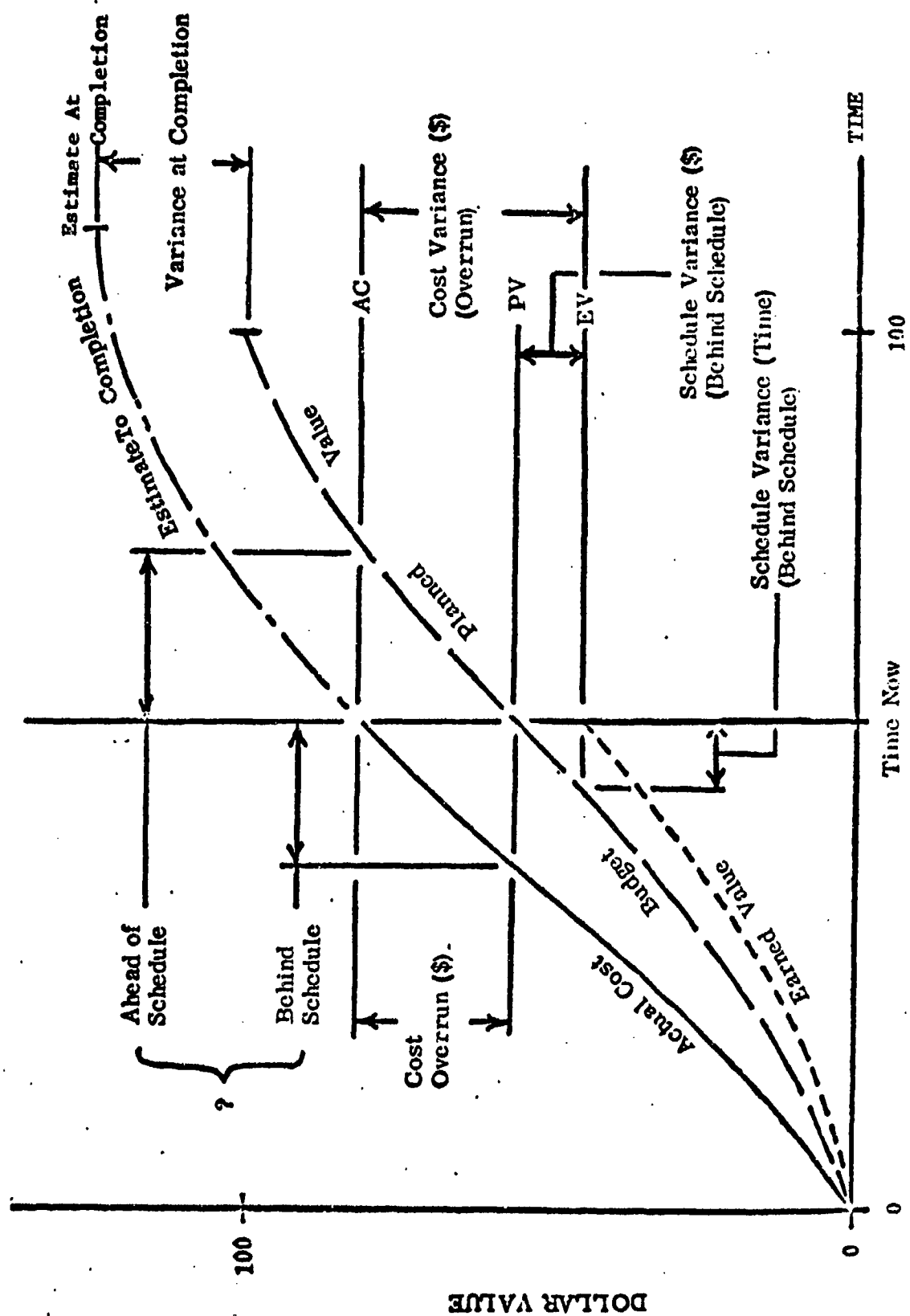
Figure 3-4. Earned Value Concept

EARNED VALUE CONCEPT
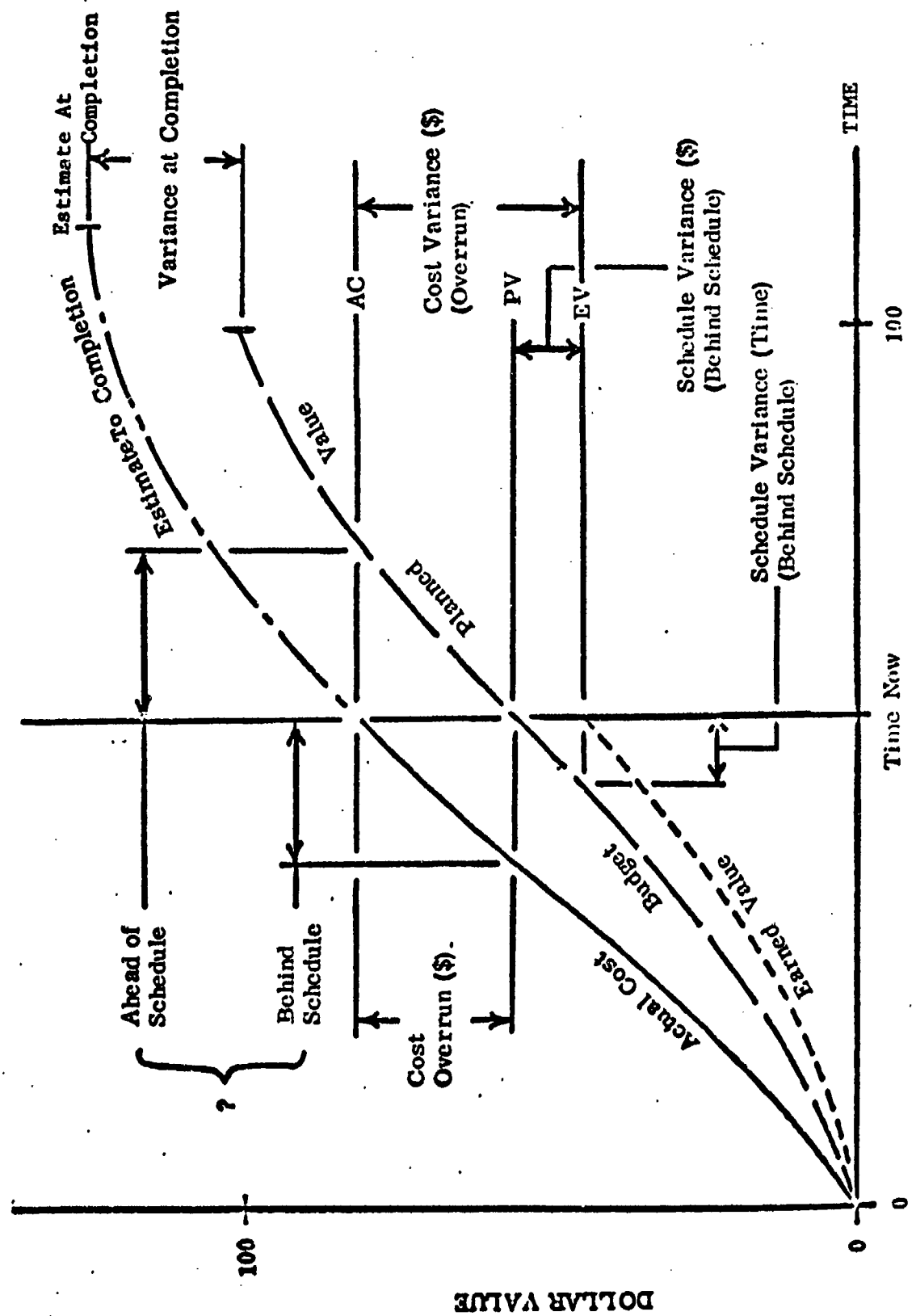
Figure 3-4. Earned Value Concept

3. Actual cost + estimate to completion = estimate at completion.
Should the reader still find the concepts unclear, a more detailed
discussion of Performance Measurement within SAIMS is given in Reference
24.

Problems and Shortcomings

From reviews of contractor's systems, certain areas stand out as
being troublesome in terms of meeting the C/SCSC. The four most common
are: (a) inadequate forward planning, (b) inability to plan and account
for materials at the point of usage, (c) lack of formal system procedures,
and (d) undisciplined budget practices (24:93).

Items (a) and (d) cause the most trouble in measuring cost perform-
ance. If the work statement has not been properly expanded and planned
the question of ascertaining contract status becomes difficult. Lack of
discipline in budgeting is the most common and the most serious problem
area. Retroactive adjustments to schedules and cost estimates and
practices which permit budgets to be shifted from one piece of work to
another frequently result in performance measurement distortions which
render the system useless. This practice, commonly called the "rubber
baseline" problem, tends to negate the earned value concept. It follows
that establishment and maintenance of a valid performance measurement
baseline which is representative of contract accomplishment is the most
basic requirement in a performance measurement system (24:93).

There are three significant shortcomings to the performance measure-
ment subsection of SAIMS. First, cost and schedule variances are measured
in value terms, namely dollars. No explicit factors (milestones) are
given for schedule status. These variances are derived from dollar figures
as shown earlier and are stated in dollars. The only calendar time reported

in the CPR is the aggregate estimate given on line 3 of the CPR Section
1 summary (see Figure 3-5) and it is not a "hard" number, i.e., it is
not traceable, but is merely average dollars per day divided into the
variance.

Section 1 - Summary:

The A-10 Program is 13.5% complete.

The cumulative schedule variance is (5.3%) which represents an
improvement of 2.2% since the last report. The behind schedule
position equates to approximately 6 work days of schedule
variance.

The cumulative cost variance is (4.9%) which is a degradation of
1.6% since the last report, is due to direct and overhead rates.

Both cost and schedule variances are well within the threshold
tolerance levels. The CPR Baseline Schedule is based on an
advanced December 1, 1974 first flight.

Figure 3-5. Extraction from the Oct. 1973 CPR

Secondly, all data is presented in point form implying a determin-
istic connotation. This is obviously not true even of performance-to-
date information simply because of the way costs are allocated to work
in progress. When forecasted figures are given, e.g., Estimate at
Completion, the uncertainties involved in the calculations are hidden
by the presentation of a single point estimate.

It is this second shortcoming which the methodology described in
Chapter 4 seeks to deal with. By considering the time and cost para-
meters as random variables and applying appropriate probability theory
and simulation implementation it is hoped that the future status of the
contract will be estimated and presented in a more realistic manner.

COST PERFORMANCE REPORT – FUNCTIONAL CATEGORIES

FORM APPROVED OMB NUMBER 22RC288

Contractor: Fairchild Industries, Inc. Fairchild Republic Co.
Location: Farmingdale, N.Y. 11735
Contract Type/No.: CPIF   F33657-73-C-0500
Program Name/Number: A-10 Full Scale Development Program
Report Period: October 1, 1973 — October 29, 1973

Organizational or Functional Category	Current Period					Cumulative To Date					At Completion		
	Budgeted Cost		Actual Cost Work Performed	Variance		Budgeted Cost		Actual Cost Work Performed	Variance		Budgeted	Latest Revised Estimate	Variance
	Work Scheduled	Work Performed		Schedule	Cost	Work Scheduled	Work Performed		Schedule	Cost			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Engineering	1,879	1,832	1,983	(46)	(151)	12,409	11,884	12,318	(525)	(434)	49,789	49,789	0
Tooling	458	512	808	54	(288)	1,552	1,342	1,962	(210)	(620)	18,994	18,994	0
Quality Assurance	59	75	78	16	(3)	266	212	261	(54)	(49)	2,768	2,768	0
Manufacturing	351	423	339	72	84	1,870	1,792	1,860	(78)	(68)	24,137	24,137	0
Material & Sub-Contract	243	393	392	60	1	1,173	1,124	750*	(49)	374*	24,752	24,752	0
Total	2,989	3,145	3,502	156	(357)	17,270	16,351	17,151	(916)	(797)	120,440	120,440	0
G&A and Admin	326	343	455	17	(112)	1,882	1,783	2,330	(99)	(447)	13,125	13,125	0
Undistributed Budget												0	
Total	3,315	3,488	3,957	173	(469)	19,152	18,137	19,381	(1,015)	(1,214)	133,565	133,565	0

(ALL ENTRIES IN THOUSANDS OF DOLLARS)

Note: This total must agree with
subtotal on Format II

Figure 3-6. CPR Functional Summary Section

The third shortcoming was not evident to the writers until well into the study. By referencing Figure 3-6 the reader will note that the CPR gives only top level functional information. Couple this format with the fact that the CPR information is from four to six weeks old by the time it reaches the SPO and it becomes evident that the program manager cannot rely on CPR information for anything more than historical purposes. What actually occurs, at least in the A-10 program, is the SPD, like the contractor, deals with problems functionally. The process of problem propagation, sometimes called the "rolling wave" concept, occurs function-ally, not along WBS branches. In the A-10 program, for example, the first big concern arose over late engineering drawings. Because the drawings were late, the processes of tool planning, design, and fabrica-tion were delayed. Manpower accession problems in the tooling area further aggrevated the problem, and so on. Succinctly put, the CPR should give a belated indication that something is wrong, but it does not tell where (see Chapter 5).

Summary. The SAIM System imposes criteria upon defense contractors that requires their management systems to be capable of providing various contract related data elements, primarily based on cost. The system suffers from two main faults: point estimation of future variances and presentation of data in value terms (usually dollars). Program managers are consequently forced to seek alternate methods for predicting future status and for tracking the time variable explicitly, (for example, expected time in days to the next significant program milestone versus the planned time to that milestone). The methodology explained in Chapter 4 is one such alternative.

IV. Proposed Methodology

This chapter annotates the specific elements pertinent to the
risk assessment methodology suggested by the AFA Risk Analysis Study
Team (see quote on page 2) and the assumptions made in applying the
methodology to the A-10 Full Scale Development Program. Basically, the
methodology employs the principles of network analysis and subjective
probability to obtain risk profiles for each of the activities of the
project and aggregates them into a risk profile for the project as a
whole through the use of advanced networking techniques. Such techniques,
like VERT (Venture Evaluation and Review Technique), use a Monte Carlo
process to repeatedly sample the risk profiles of the individual
activities and arrive at a distribution for the entire project. For
a more detailed explanation of VERT, see Appendix C.

To illustrate how this technique works and show the information
required, an example is in order. Suppose, for simplicity's sake, we
have a program made up of two subsystems, A and B. In order to complete
the project, A and B must be completed and then integrated and as-
sembled, activity C. This is shown in Figure 4-1. Associated with each
of the three activities are probability distributions for cost and
time. (The triangular distribution was assumed in the example.) In
reality, the project activities would occur only once; however, using
network simulation, one can repeatedly sample from these distributions
to determine cost and schedule histograms for the total project. The
VERT output is in the form of probability density functions (pdf) and
·cumulative density functions (cdf). The risk profile can be obtained
from the output by the formula, 1-cdf. The resulting risk profile, say
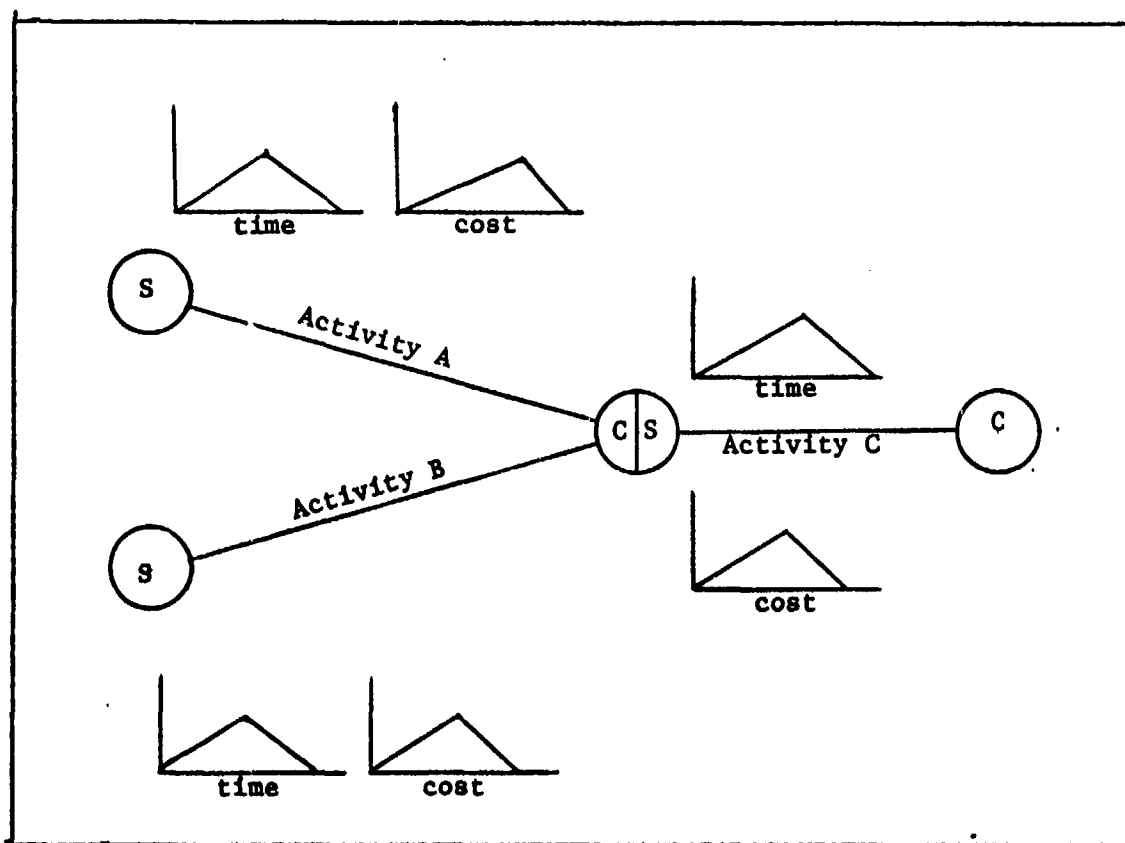for time, might look something like that shown in Figure 4-2. The

Figure 4-1 Simple 3 Activity Simulation
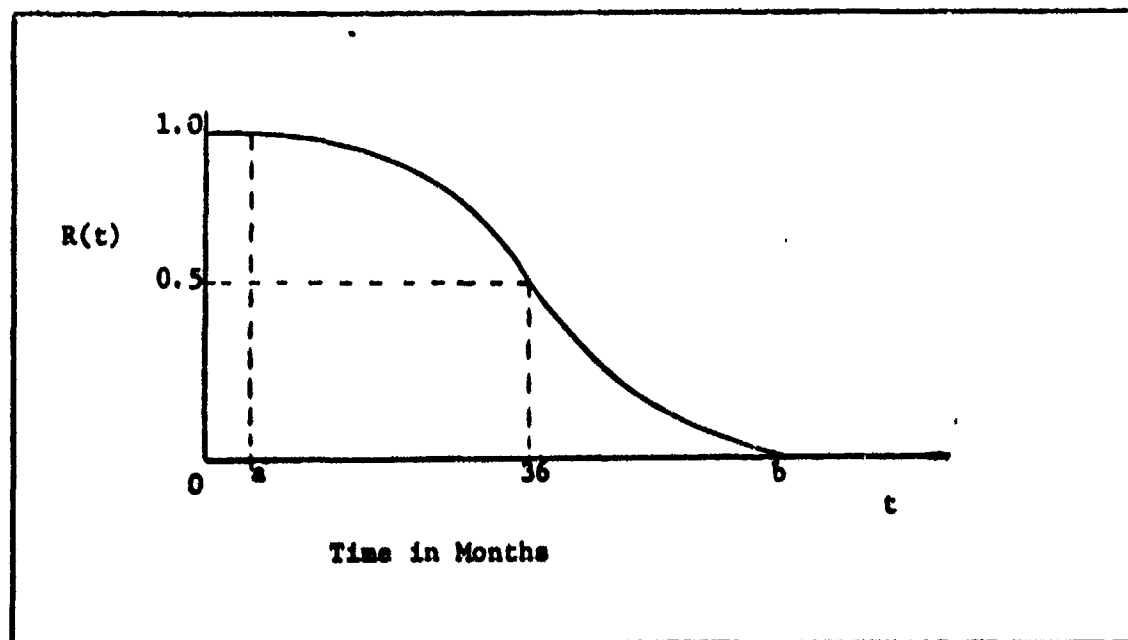
Figure 4-2 Risk Profile (time)

area of uncertainty is between a and b. As illustrated, the probability of not completing the project in the 36th month is 0.5.

The basic objectives in applying this methodology were then to (a) formulate an activity network of the A-10 Full Scale Development Project, (b) obtain the best possible time and cost estimates for the network activities, and (c) use VERT to analyze the network using pdf's derived from the subjective estimates. We hoped that this methodology would provide the program manager with information that would compare CPR data and afford lower WBS level traceability for problem analysis. Also, sensitivity analysis could be performed by varying the parameters of the distribution to determine the effects of different inputs and to discover which activities have the greatest propensity to increase risk.

The accuracy of this risk assessment methodology is primarily dependent on the realism of the network and quality of the time and cost estimates. This would suggest a very elaborate and detailed network and the use of the most advanced techniques for soliciting subjective probabilities. However, other requirements such as simplicity and practicality were also germane to the methodology, not to mention the three month time constraint for the thesis itself. A detailed network implies large numbers of activities which increases the network construction and maintenance time and also the data collection efforts, especially when subjective probability solicitation is used. There are several elaborate methods available in the literature to obtain subjective probability estimates (6:17). Such methods as the "You Bet Yourself", "Fit Values to the Shape", and "Delphi" require considerable time and administrative effort to obtain the distributions. Therefore, it was necessary to make some trade-offs between the requirements for

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accuracy and those of the real world.

Network

As mentioned, the most difficult requirement for the network was to limit the number of activities in order to bound the data collection process, yet still produce a realistic network. We hoped to build a network based on the Work Breakdown Structure explained in Chapter 3. These WBS elements (level four and above) provide the basic units by which the contractor reports cost and schedule information to the Systems Program Office, the Air Staff and other governmental agencies. The contractor primarily monitors the program functionally, that is, he breaks the project down into functional tasks such as design, tooling, manufacturing, quality assurance, and procurement. These tasks are further sub-divided into work packages; however, to construct a network at this level and aggregate to the upper levels of the WBS would have been a monumental undertaking. By basing the network on the WBS elements, we thought we could limit the total activities to a manageable number. SPO and contractor personnel felt that this type of network was feasible and would provide enough realism to make the methodology valid. In addition to the above, there were three other important requirements in establishing the network: (a) activities must be clearly defined with start and stop points, (b) relationships between activities must be known, and (c) each activity must have at least one cost expert and one time expert in order to obtain complete data.

Since the A-10 Full Scale Development Program covers the time span from March 1973 to September 1976, we decided to track the program to July, 1975. This is a significant milestone date in the program as

the gun and second DT&E aircraft are to be mated and demonstrated by
this time. This decision was made for two reasons: (a) to limit the
number of activities in the network and (b) to improve the quality of
the estimates by not requiring the experts to predict events too far
into the future.

Data

To obtain subjective probability estimates, it is necessary to
solicit data from knowledgeable individuals and fit this data to an
appropriate probability distribution. Four pertinent questions need
to be answered.

First, who should provide the subjective input? SPO personnel
have some knowledge of the individual WBS elements, but their know-
ledge of the project is primarily dependent on data provided them by
the contractor. This prompted us to go directly the contractor personnel
for our data sources. As mentioned in Chapter 3, the contractor's
management system is functionally made up of sets of cost accounts and
each cost account has a manager who is responsible for input data (BCWS,
BCWP, and ACWP). We thought that these individuals could provide us with
the best cost information; however, in a few areas, such as Final Assembly,
it would be necessary to obtain time estimates from shop supervisors
responsible for that particular task.

Secondly, which subjective assessment technique should be used? As
pointed out in the Tripp-Leedom Report, the major difference between
estimates is due not to different assessment techniques but to the test
subjects themselves (50:28). Such techniques as Delphi and Standard
Gamble require considerable time to gather the data, while others like
the Curve Fitting techniques require at least a basic understanding of

probability and statistics. In keeping with the requirements for simplicity and practicality, we decided to use the three point method which has been used often in the past as an approximating technique in PERT (Program Evaluation Review Technique) (36:12). In this technique the subject is asked to state his most likely estimate for cost and time and his lowest and highest possible estimates. These three estimates are then used for formulate a cost and time probability density function for the activity.

Thirdly, since the underlying distribution for the estimates is unknown, which distribution should be assumed? The most widely used distribution has been the Beta distribution (6:97). It has been used in the PERT methodology and Bevelhymer assumed it in his study (10:28). The World Bank has compared several distributions fitted to subjective probability estimates in their investment projects and found, in retrospect, that the triangular distribution would have obtained an estimate remarkably close to their actual results (41:13). They think that the Beta distribution incorrectly weights the value assigned to the "most likely" estimate. In their experience, the most likely estimate is not a reliable datum, and in practice it often lies between the value with the highest probability (mode) and the mean. The triangular distribution is simple and easy to use. Since there is debate as to which distribution is more valid, we assumed the triangular distribution for both cost and time. A derivation of the triangular distribution's parameters and properties is given in Appendix B.

The fourth and most difficult question to answer is: How does one get the contractor personnel to provide honest, unbiased opinions of the cost and time ranges? This probably is the most critical area in

terms of whether the methodology is useful or not. Since the cost
account manager is the "expert", his estimate must be accepted as
the most valid as long as he feels that it corresponds with his best
judgment. All too often the personnel who are in the best position to
provide sound estimates may also have a vested interest in distorting
them (56:96). For example, the persons being asked their probability
assessment may not have an incentive for supplying the estimate which
they believe to be the closest to the actual cost or time ranges.
Reasons for these vagaries are difficult to ascertain and control. The
assessor may be trying to hide an internal deficiency within his area
of responsibility or may want to "pad" the estimate to look good at the
completion of the program. In this situation, where the government
(SPO) is trying to obtain information from the contractor there is even
more potential bias since the contractor may be reluctant to provide
outside organizations with information that may be adverse to his
interests. Woodgate suggests that one possible way around this difficulty
is to instill a sense of participation in the project as a whole by
fostering a team spirit and placing emphasis upon the overall project
objectives rather than individual department accomplishments (56:96).
Such a sense of participation cannot be enforced. It is a philosophy
engendered by top management and developed over a relatively long period
of time.

Another possible incentive for giving good estimates is the use of
scoring rules or penalty functions (38:1108). These methods pretend
to provide motivation for the expert to be honest and express his true
feelings. In the case of scoring rules, the subject is provided feed-
back on how well his estimates have correlated with actual results.

Penalty functions are used much in the same manner except the subject
is penalised in some way if his predictive values are not within
predetermined bounds of the actual value. The techniques are not
feasible in the weapons acquisition process as frequent iterations
are required to compare predicted values with actual results. The
outcome of a research and development project occurs only once and may
not be known for many months, if ever.

Another possible technique is a group assessment method like
the Delphi technique. A number of experts anonymously provide pre-
dictive estimates along with justification for their values. After
each response, the experts view the group responses and justifications
and make adjustments to their previous estimates. After several
iterations of the process, the group usually arrives at some consensus
opinion. The primary drawbacks to the technique are (a) the requirement
for several knowledgeable experts and (b) the large amount of time
necessary to process the iterations.

The last technique to be discussed, and the one to be used in
this methodology to hopefully motivate honest, unbiased estimates
is one that the writers have called the semi-inducement method. Its
use has limited application as there is a requirement to have a
second source of "semi-experts" who have some knowledge of activity
times and costs. Such a situation exists in the relationship between
the SPO and the contractor. The SPO personnel are charged with mon-
itoring these variables and have some knowledge of their status. The
questioner can use this external information to compile information
on each activity so that he has some prior knowledge of the ranges
of cost and time values when he solicits them from the primary

sources. This information is used to "remind" the subject of certain factors that may have an effect on his estimate. For example, if the expert in quality assurance gave what the solicitor knew to be a low cost estimate for a particular series of tests that were partially complete, a reminder that his account is presently x dollars over budget cost and y dollars behind on earned value might prompt him to re-consider his estimate; but, in the final analysis, the primary expert's estimate can not be totally rejected.

Summary

The methodology consists of constructing a realistic summary network of the A-10 Full Scale Development Project up to the time the second DT&E aircraft is to be mated with the 30mm gun. The network is based on WBS elements to afford comparison with CPR data and reduce the number of activities to a manageable size. The data is based on the principles of subjective probability and will be obtained from contractor personnel using the three point assessment method. These estimates are then fitted to the triangular distribution to obtain the required time and cost probability density functions for each of the activities. The risk profiles for the individual activities are computed and aggregated using the VERT simulation routine to obtain overall risk profiles for schedule and cost.

Further References

It should be noted that the areas of network analysis and subjective probability estimates are quite vast and controversial. This thesis in no way has addressed all the alternatives, assumptions, and limitations associated with these two principles. For those

interested in a more theoretical and detailed explanation of these
subjects, the following references are suggested: 5,6,8,11, 25,36,45,
48,52,54 and 56.

V. A Test Application

Constructing the Network

The first step in applying the methodology was to construct a simplified, but realistic, WBS network of the A-10 project. Although neither the Contractor nor the SPO was using a PERT project network, it was hoped that the Contractor's Management Network, a portion of which is depicted in Figure 5-1, could be used to construct a network suitable for this application. Further study of the Management Network revealed that its activities are not clearly defined. For example, in Figure 5-1, top line, there is a node indicating completion of Design Layout, but we have no idea from the network when the activity, "Design Layout" was started. In the second line, it is undetermined as to whether Tool Pre-planning is completed at the start of Tool Planning or whether these two activities are concurrent for a period of time. It is primarily an event oriented network with nodes representing contract milestones and/or functional events. Initial attempts to identify the activities implicit in the event network and determine interdependencies, indicated that the resulting network would include too many detailed activities, making the application impractical under the constraints of the research.

A more simplified network was constructed using the Contract Work Breakdown Structure Dictionary, a contractor document which lists the WBS elements to as low as the sixth level and provides the link between these elements and the functional structure via cost account aggregation. This network, a portion of which is shown in Figure 5-2, showed promise of meeting the requirements and constraints annotated in Chapters 2 and 4. Both the Contractor and SPO advisors expressed con-
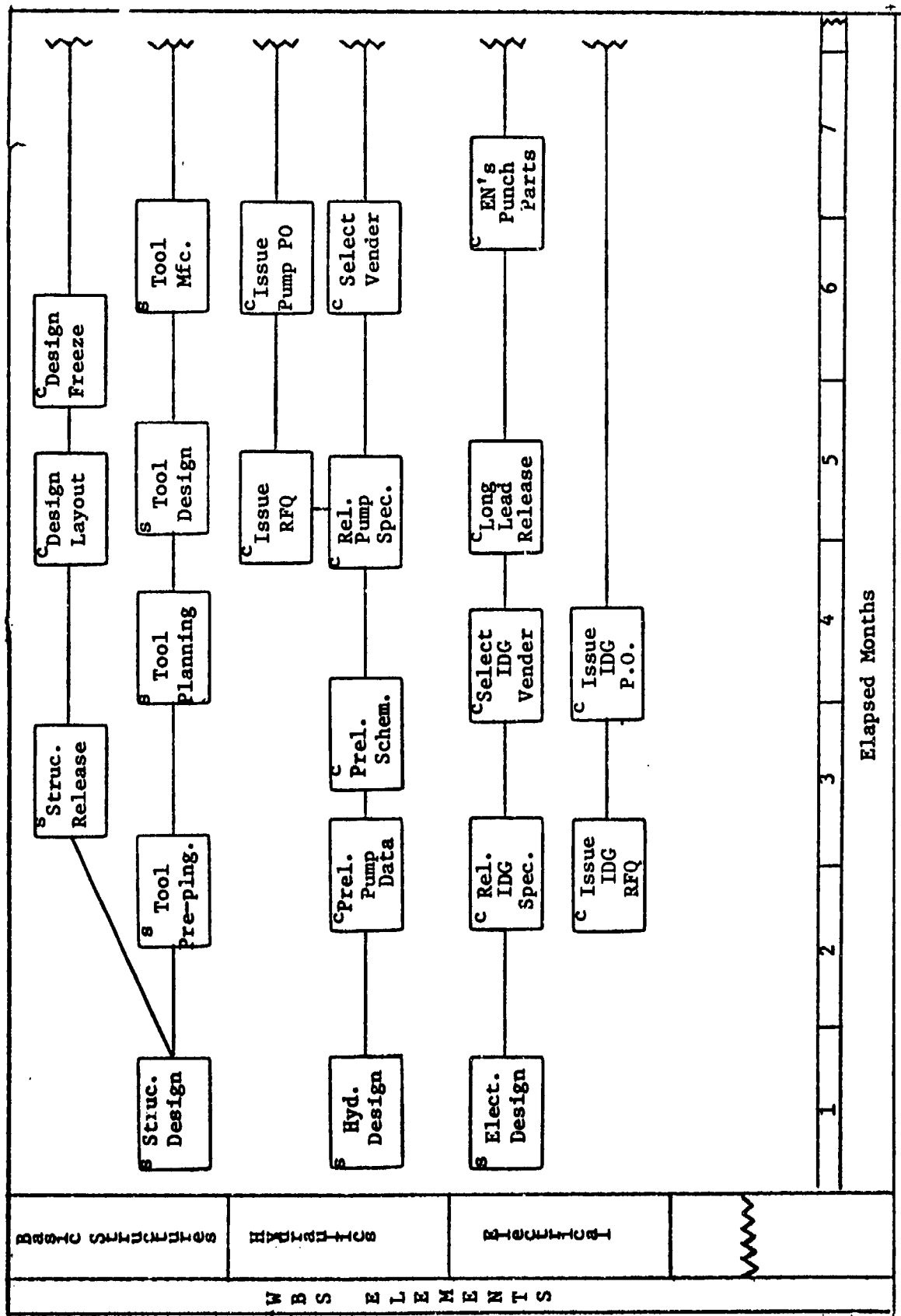
Figure 5-1   Contractor's Management Network
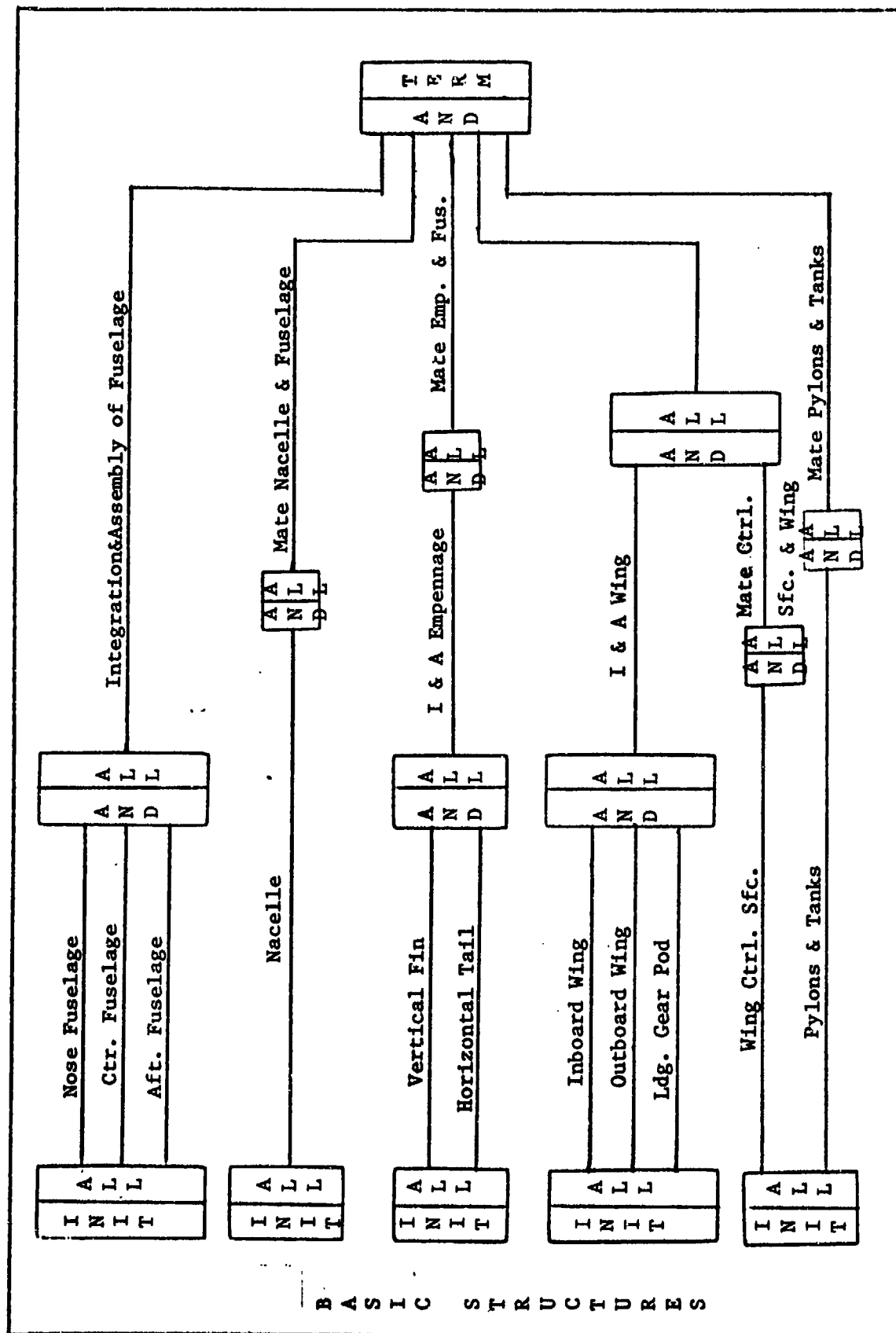
Figure 5-2 Segment of WBS-Based Network

fidence in the potential realism of the network. Before finalizing
the network and coding it into the VERT simulation routine, a pre-
liminary data collection effort was made to insure that the data
sources could provide the necessary estimates for each of the
activities. A portion of the network was selected for the trial run.
This first attempt in obtaining time and cost estimates surfaced
major problems in the application of the methodology.

The major problem was correlating the data sources with the
activities. In short, we were unable to find experts within the
Contractor's organization who could provide aggregate time or cost
estimates for an entire WBS activity. The crux of the problem lies
in the relationship between WBS and functional structures. This
relationship is illustrated in Figure 5-3. As depicted, a number of
functional departments contribute to the construction of the
Forward Fuselage section. Also, the activities of these different
departments are intertwined with activities dependent upon other
activities before start or completion can occur. For example, look-
ing at Figure 5-3 again, the functional tasks of design, tooling,
and procurement are related in that some of the design effort must
be completed before tool planning or procurement operations can be-
gin. Also, all the engineering design must be completed before the
tooling activity can be finished. It is very difficult to determine
just exactly how far along one activity must be before another can be-
gin. In order to determine information of this detail, one would have
to network the project at the work package level. There are approx-
imately 3000 work packages in FRC's portion of the program. This
WBS/functional relationship is prevalent throughout most of the other
WBS elements. In order to obtain cost and time estimates, the expert

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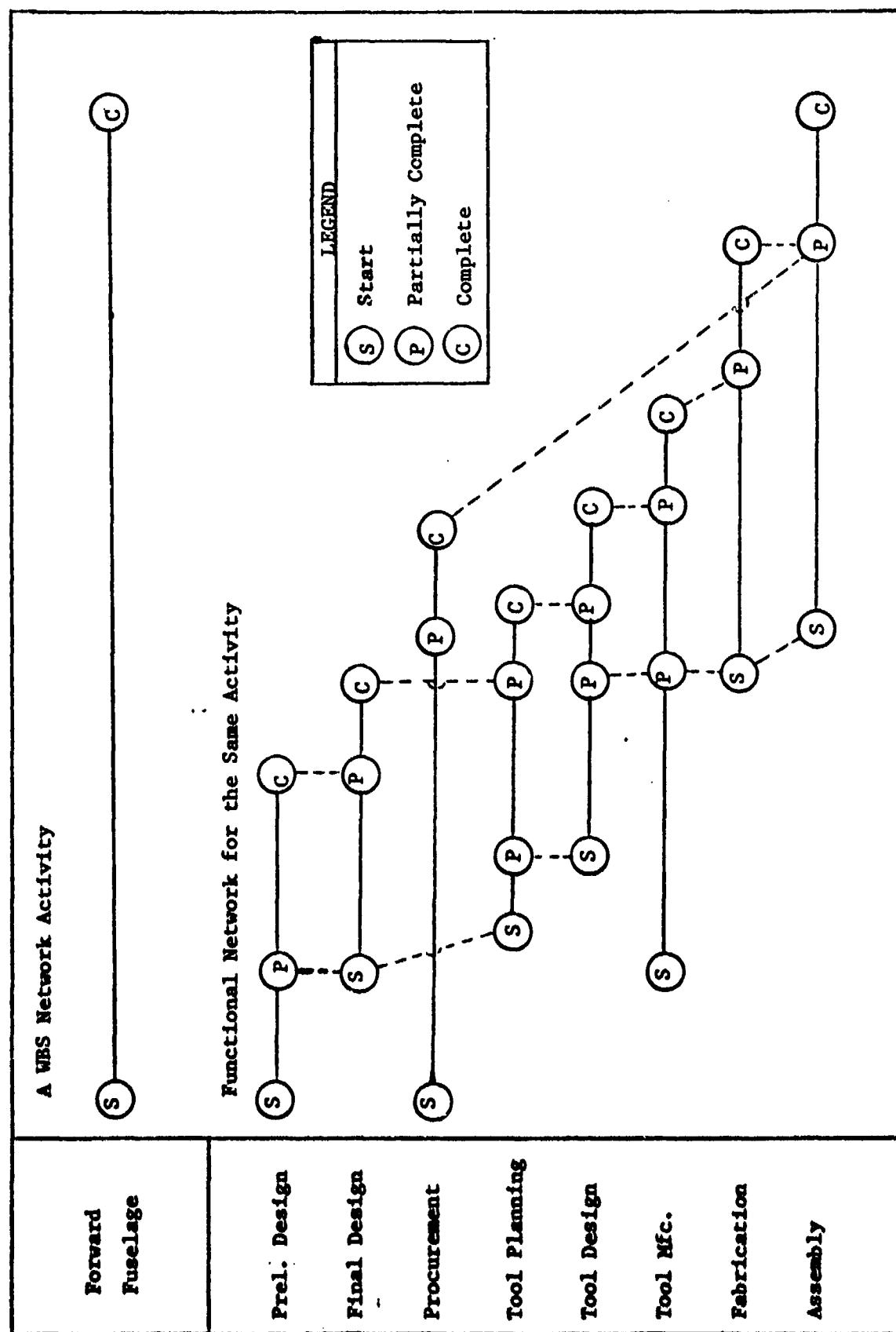
Figure 5-3 Comparison of WBS and Functional Networks

must have sufficient knowledge of the different functional tasks
that are necessary for the completion of a particular WBS element.
Since the contractor manages through functional organization, e.g.,
he "tracks" the project through the planning and control of his engin-
eering, tooling, quality assurance, manufacturing, material, and sub-
contracting functions, few of the contractor's middle management
personnel, such as the cost account managers, are in a position to
know how much other functions contribute to a particular WBS element.
They are very knowledgeable in their specific functional area but do
not have the breadth of knowledge necessary to express cost or time
estimates for an entire WBS activity.

The alternatives to this dilemma were to (a) find suitable experts
knowledgeable of the existing WBS activities or (b) sub-divide the
activities into specific functional cost accounts and thus permit the
cost account managers to make judgements on those tasks within their
area of responsibility. With the exception of a few elements like Final
Integration and Assembly, Quality Assurance, and Procurement, contractor
personnel knowledgeable of the WBS activities were non-existent. One
can easily see, changing from a WBS-based network to a functional net-
work causes the network to explode. As depicted in Figure 5-3, the
number of activities increases from 1 to 32 (19 activities and 13
transportation arcs). The initial WBS-based network contained
approximately 70 activities, most of which increase by a conservative
factor of 20 if a functional network were constructed. The resultant
network would have contained about 1400 activities. The data
collection process would then have been enormous.

Soliciting Estimates

Further problems were encountered when we attempted to solicit time estimates for the final assembly phase. Although the assembly task had been planned in detail, the production planner in charge of the operation indicated that deviations from the plan would occur, especially during the first few DT&E aircraft. Some parts would not be available on time and problems would occur requiring re-design or re-fabrication. However, he maintained that the assembly operation would not come to a standstill just because the next step in the plan could not be completed. "Work-around plans" would be implemented, circumventing problem areas and rescheduling them out of sequence. He did not know exactly how many work-around operations would be required but did mention that over a hundred was not unlikely. Due to these potential work-around requirements, he was very reluctant to commit himself to estimates for the assembly activities. For example, according to the plan, the three fuselage sections are to be fully "stuffed" with appropriate hydraulic and electrical components before the sections are mated. The production planner was reluctant to commit himself to this sequence of activities. He argued that the mating operation could take place earlier if some of the hydraulic or electrical components were not available on time. These late components would then be assembled at a later point in the assembly operation. Some contingency plans were already being formulated at the time of this interview since it was already known that a few long-lead items would most likely be late.

The existence of these possible work-around operations causes further woes for the networker. Because numerous changes are expected in the network activities during the construction of the first few

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DT&E aircraft, frequent, perhaps daily, updating will be necessary
in order to maintain currency. Since the network was to be main-
tained by the SPO, it would have required a great deal of coordination
between the contractor and SPO to maintain a realistic network.

Bias Problems

As expected, but to a greater degree than anticipated, the problem
of soliciting unbiased estimates was encountered. As mentioned in
Chapter 4, we hoped to reduce the bias by gathering as much cost and
time information available about each activity prior to interviewing
the experts to obtain their predictive estimates. In two areas of
quality assurance we were able to find contractor personnel capable of
providing cost estimates for two WBS activities. In both of these cases,
their initial estima es were considerably lower than we had anticipated.
The Cost Performance Report indicated that these two accounts were
approximately 15% over their cumulative budget-to-date, but would be on-
target at the end of the program. Information from SPO personnel
indicated that the overrun was greater than the CPR information and that
it was highly unlikely that they could be reduced significantly. After
over a half hour of discussion, both cost account managers revised their
estimates to higher, more realistic values. They later admitted that
they were very reluctant to provide individuals outside the organization
with information that deviated from that reported through the formal
reporting system, i.e., the CPR. The fact that we appeared to have
accurate information about their accounts in the pertinent WBS activities
prompted them to revise their estimates.

It appears that the semi-inducement technique has some potential to

reduce gross bias in the estimates but it also has major shortcomings. It can only be applied to those situations where external information is available. Even if the prior information is available, substantial research effort is required to assimilate the information. Using a network approach, one must limit the number of activities to avoid an expensive and time consuming data collection process. There is also the possibility that the technique itself might bias the estimates. An aggressive interviewer could possibly influence the expert to estimate values inconsistent with his own beliefs. The number of samples taken were too small to prove or disapprove this possibility.

Summary

We were unable to construct a WBS-based network that was consistent with the network requirements established for the methodology. Possible work-around operations pertinent to the construction of the first few development aircraft further complicated network construction, maintenance, and data collection. Finally, the efforts made to solicit cost and time estimates indicated considerable reluctance on the contractor's part to provide us with unbiased estimates. The magnitude of these problems prompted us to abandon the methodology as impractical and seek alternate ways to assist the SPO in assessing contractor performance.

VI. Least Squares Forecasting

Subsequent to concluding that our application of the original methodology on a scale detailed enough to afford realism was not feasible in the time alloted, we sought other ways to forecast cost and schedule performance. Time prevented us from investigating all considerations so we pursued two approaches based on least squares regression analysis. This chapter reflects those efforts.

Motivation

Motivation arose from observing the monthly CPR data, specifically the "At Completion" column. By referencing Figure 6-1, the reader will note that the Estimate at Completion is precisely equal to Budget at Completion although there exist several cases of adverse cost variance (indicated by parenthesis) in the Cumulative to Date Section. This implies that for those elements with adverse cost variance (overrun) the contractor's estimate to completion was arrived at by "backing in," i.e., somehow he will perform the remaining work for exactly the current adverse variance dollars less than is budgeted.

Both the contractor and the SPO acknowledged this was not possible in some cases and the contractor was admonished to correct the situation. The December 1973 CPR is the first to show non-zero variances at completion but there still is a question. Those non-zero variances at completion are just equal to current (December) cost variances, as in Figure 6-2. The contractor simply added current variance to Budget at Completion to arrive at Estimate at Completion. Given this sequence of events, we questioned whether or not the contractor was really attempting an accurate forecast. The FRC Management Control and Information System (MCIS) Training Manual states:

Figure 6-1. October CPR

COST PERFORMANCE REPORT – WORK BREAKDOWN STRUCTURE

Contractor: Fairchild Industries, Inc.
Fairchild Republic Co.
Location: Farmingdale, N.Y. 11735

Contract Type: CPIF F33657-73-C-0500
Program Name: A-10 Full Scale Development Program
Report Period: November 25, 1973 – December 31, 1973

Work Breakdown Structure	Budgeted Cost Work Scheduled	Budgeted Cost Work Performed	Actual Cost Work Performed	Variance Schedule	Variance Cost	Budgeted Cost Work Scheduled	Budgeted Cost Work Performed	Actual Cost Work Performed	Variance Schedule	Variance Cost	Budgeted At Completion	Estimated At Completion	Variance
A-10 SYSTEM A-10000 AA	5,223	5,656	6,061	427	(433)	26,769	26,160	27,173	(589)	(1,013)	122,296	121,303	(1,013)
AIR VEHICLE A-10100 TA	3,349	3,733	4,193	404	(459)	15,902	14,729	15,872	(282)	(1,153)	67,636	63,656	(1,152)
AIRFRAME A-11100 UA	3,349	3,753	4,116	404	(363)	14,732	14,459	15,641	(282)	(1,191)	64,551	63,412	(1,191)
INTEGRATION & ASSEMBLY A-11110 UB	262	298	223	56	67	2,516	2,447	2,497	(71)	(30)	5,029	5,039	109
BASIC STRUCTURES A-11120 1A	2,682	3,031	3,597	348	(566)	9,829	9,662	18,919	(167)	(1,257)	46,151	67,968	(1,257)
VEHICLE POWER A-11130 WE	180	194	151	14	63	1,022	982	946	(79)	86	5,364	5,271	86
ENVIRONMENTAL CONTROL SYSTEM A-11140 W1	16	20	20	4	0	102	102	94	(1)	0	479	479	0
FLIGHT CONTROL SYSTEM A-11150 W2	118	164	54	(14)	10	985	610	615	15	5)	2,659	2,654	9

Figure 6-2. December CPR

The [Estimate to Completion] ETC is a fresh objective re-analysis of the remaining work to be done independent of the budget or actual costs to date... Particularly if the ETC's are larger than expected, analysis and ETC's at the Work Package level should be performed to pinpoint the source of the problem (17:135).

At the suggestion of members of the Program Control Directorate in the A-10 SPO, we decided to try some simple regression analysis as a first approximation to improving the CPR variance forecasting. It is well to note again that SAIMS schedule data is measured in dollars, not days.

The Linear Model

We first chose to attempt an analysis on the cost account level with the option of summing those numbers and repeating the process on some higher level, either WBS or functional. Toward that end we obtained data from two FRC MCIS reports, the Project Cost/Schedule Comparison Report and the Planning Package Status Report, for months May through November 1973. Although the contract was signed on 1 March 1973, the first SAIMS data did not result until the month of May, hence the two month lag. The model used was the same for both time and cost variances, as well as for direct labor hour variances (an additional data item obtainable from the two reports). Since there can be no variance prior to contract initiation, we omitted the intercept term and used an equation of the form

$$y_i = Bx_i + e_i$$

where y_i is the observed variance on data set i, x_i is the independent variable (months or BCWS) for set i, B is the parameter (coefficient) to be estimated, and e_i is the measurement error for set i. The e's are assumed to be independent with mean zero and variance $sigma^2$, a constant. For analysis of variance purposes, the e's are also assumed to be normally distributed (here we mean variance in the statistical

sense).

Since some cost accounts did not open at contract initiation we had at most seven data points. We concluded that the Full Scale Development effort would have been too large (313 cost accounts) so we limited the analysis to the Basic Structure element defined in Chapter 2. Further, since most recurring cost accounts (those that would have entries periodically for each of the 10 DT&E aircraft) were not open, we omitted them. Through an oversight we also ommitted two non-recurring cost accounts. The result was that we had 37 cost account data sets. Each set contained BCWS, BCWP, ACWP, Budgeted Labor Hours, and Actual Labor Hours. We also obtained BCWS numbers for the relevant cost accounts through June 1974. A typical data set is shown in Table 6-1.

BCWS	BCWP	ACWP	BUDGETED LABOR HOURS	ACTUAL LABOR HOURS	Month
62600	62599	61490	4198	3757	May 73
103819	99047	93633	6646	5886	Jun
192794	173018	186036	11622	12250	Jul
367333	294932	374721	19817	25059	Aug
562132	491659	616583	33048	41532	Sep
580413	564559	760687	37977	51144	Oct
645574	645812	851250	43481	57118	Nov
686685					Dec
712015					Jan 74
741217					Feb
757903					Mar
1012251					Apr
1012251					May
1012251					Jun
Cost Account - 019B - Engineering, Fuselage I&A					

Table 6-1. Typical Data Set

Implementation. We used the OMNITAB program on the GE 600 series computer to perform the analysis (29). By arranging the data sets in the OMNITAB worksheet we were able to write a simple program (Appendix D) to do the arithmetic and perform the regressions. We also used the

automatic plot feature of OMNITAB to print the graphs in Figures 6-3 through 6- 6. Figure 6-6 is a prediction similar to Figure 3-4.

Findings. The results of the program were questionable. First, the omission of the two non-recurring accounts and all the recurring accounts made the totals lower than those reported on the CPR. For instance, the November CPR listed the Basic Structure cumulative-to-date BCWS as $7,147,000 (to the nearest thousand dollars) and our data showed $5,727,614. By adding those cost accounts omitted from our data we could show a November BCWS of $6,997,636. We cannot explain the 149 thousand dollar difference.

Secondly, our cost variance prediction routine was necessarily a two step procedure and hencethe linearity assumption was suspect. The reader will recall from Chapter 3 that cost variance equals earned value minus actual costs. This implies that a future estimate of actual cost must be the sum of a predicted earned value and a predicted cost variance. To find the predicted earned value, we regressed earned value against BCWS as the independent variable. To find predicted cost variance, we regressed cost variance-to-date against months one through seven. Table 6-2 lists the equations. Table 6-3 lists a summary of the results. The large 95% confidence intervals emphasize the uncertainty of the process.

Thirdly, we were skeptical of the information displayed in Figures 6-3 and 6-4. Note the simultaneous decrease of cost and schedule variance. Generally when a contractor is behind schedule, he must spend dollars (overtime) to catch up, but this did not happen is this case. The only possible explanation within the C/SCS Criteria is that a peculiarly large block of earned value was accrued in November. Regardless, the data jump reduced the reliability of a linear model.
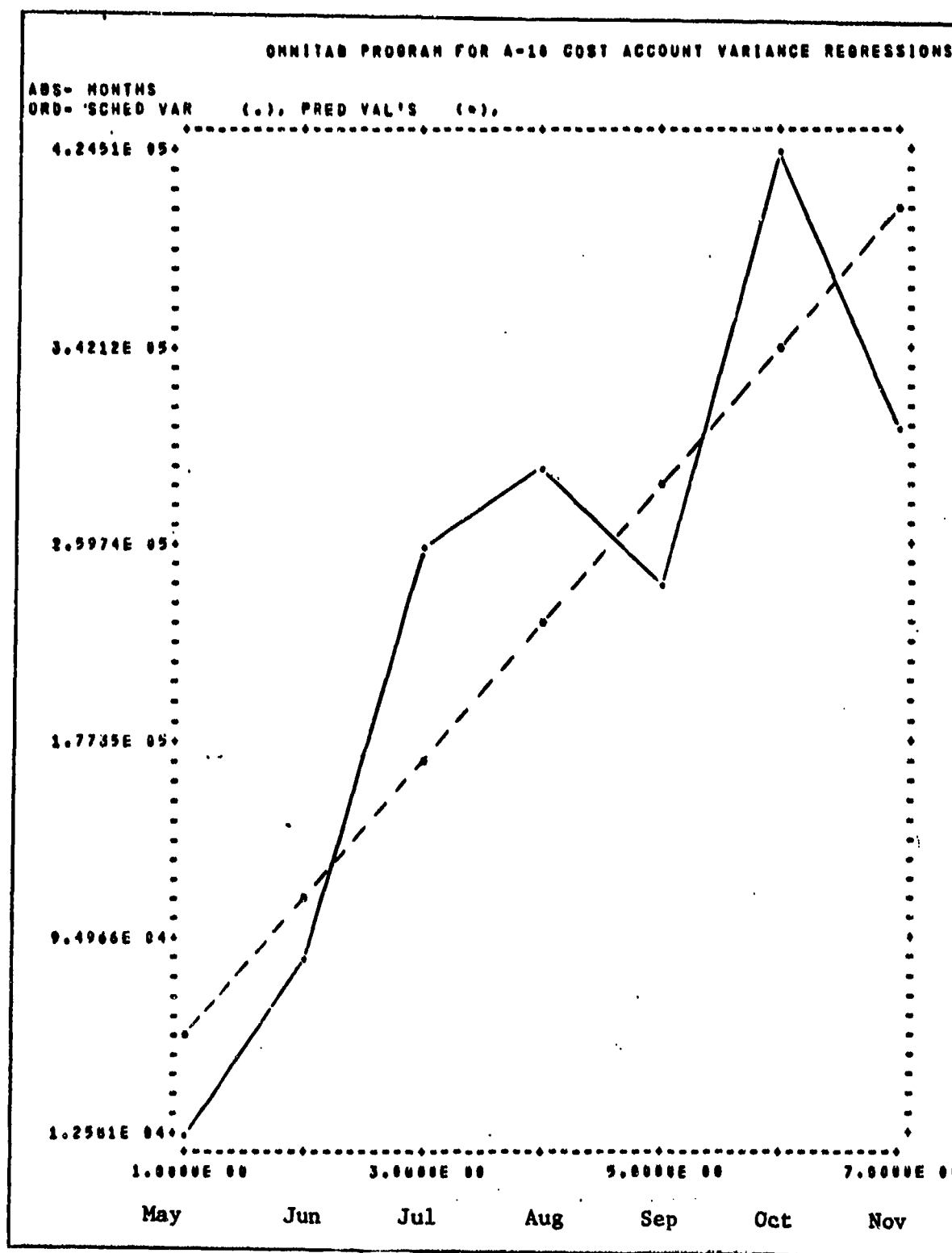
Figure 6-3. Actual and Predicted Schedule Variance
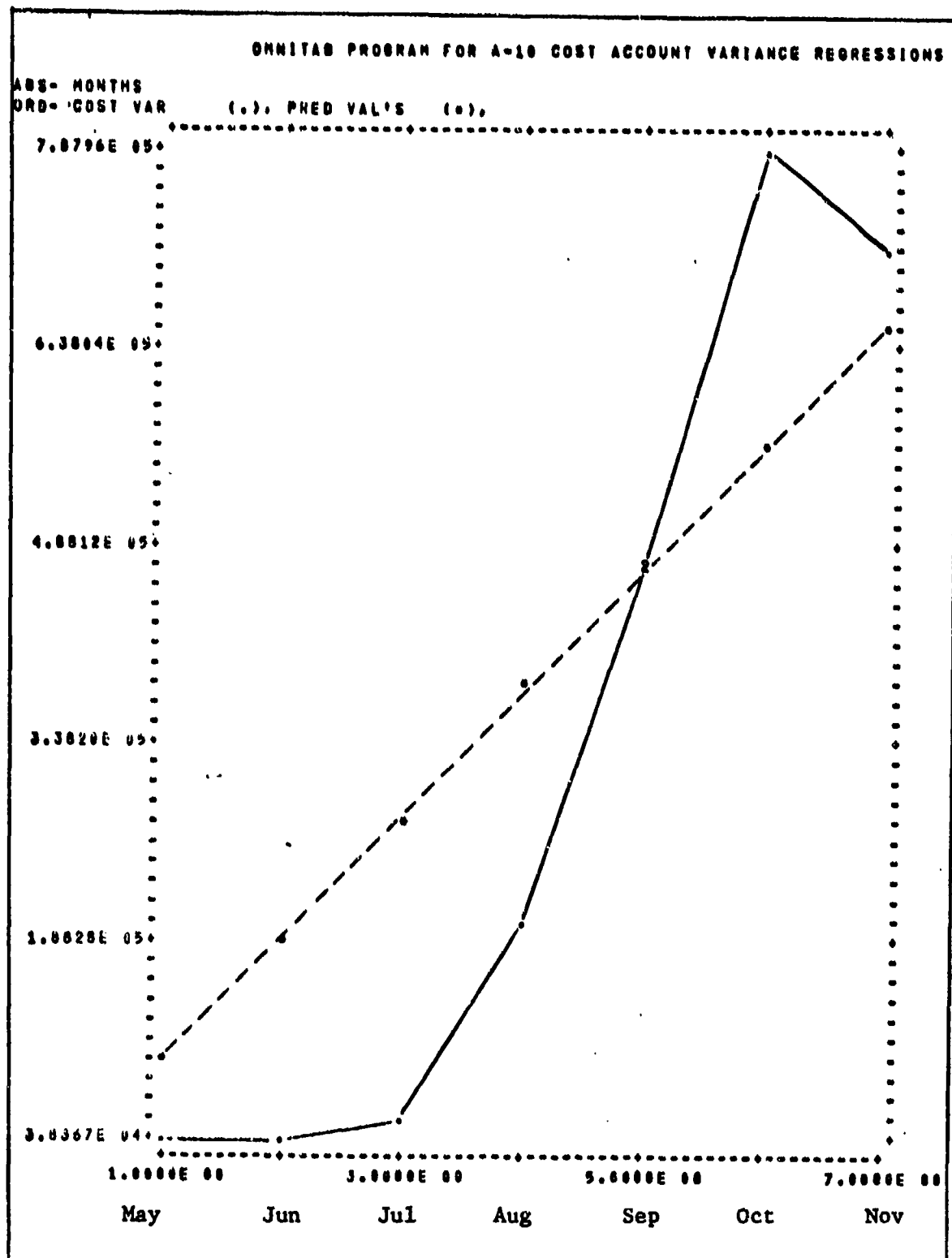
Figure 6-4. Actual and Predicted Cost Variance
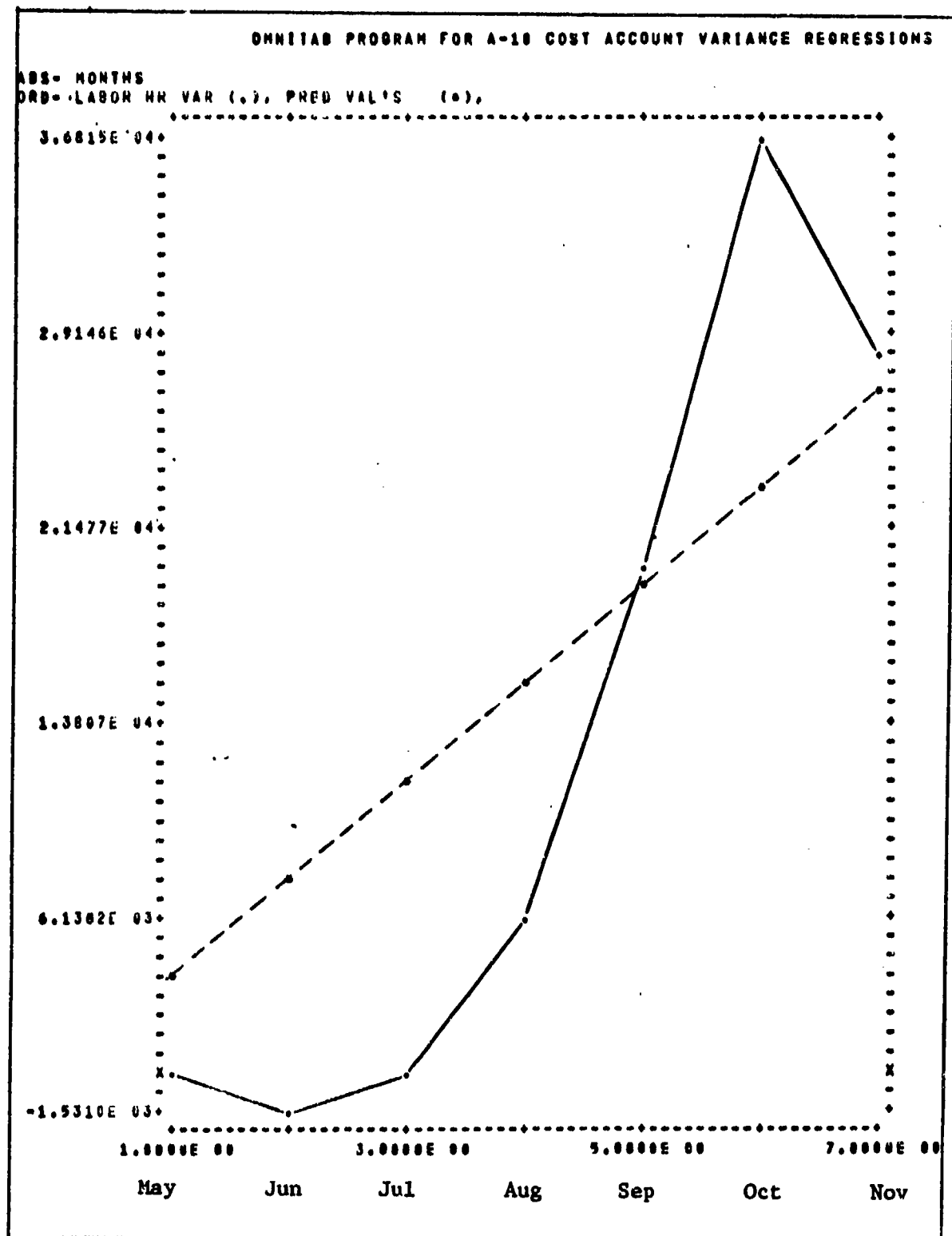
Figure 6-5. Actual and Predicted Labor Hour Varaince

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                    OMNITAB PROGRAM FOR A-10 COST ACCOUNT VARIANCE REGRESSIONS

ABS- MONTHS
ORD- BCWS MAY-JUN (.), EARNED VALUE (*), BCWP+CST VAR (+),
NO. OF PTS. PLOTTED    42 NO. NOT PLOTTED (OUT OF BOUNDS)      0

    2.0000E 07+ BCWS MAY-JUN    EARNED VALUE    BCWP+CST VAR

                319110.00       306337.00       346958.00
                624540.00       541825.00       588192.00
                1093943.0       834045.00       893693.00
                1555536.0       1262911.0       1459269.0
                2478821.0       2236441.8       2715465.0

                3778038.0       3393530.8       4141486.0
                5727614.0       5416807.0       6131134.0
    1.6000E 07+ 8707524.0       7981544.9       8736097.9
                10641545.       9754319.4       10603191.
                12202536.       11185165.       12128356.

                14324162.       13129303.       14167413.
                16037931.       14700788.       15832618.
                17901110.       16408627.       17634776.
                18619421.       17867850.       18387517.


    1.2000E 07+



    8.0000E 06+



    4.0000E 06+


    0.          X                                                            X

            0.0000E 00          4.2444E 00       8.6667E 00       1.4000E 01
            May 73                              Nov 73                     Jun 74
```

Figure 6-6. Predicted Performance Through June 1974

1. Predicted Cost Variance = f_1 (Actual Cost Variance, Months)
$$CV_p = f_1(CV_a, M)$$
$$CV_p = B_{cv}M$$

2. Predicted Earned Value = f_2(BCWS, Actual Earned Value)
$$EV_p = f_2(BCWS, EV_a)$$
$$EV_p = B_{ev}BCWS$$

3. Predicted Actual Cost = Predicted EV + Predicted CV
$$AC_p = EV_p + CV_p$$

4. Predicted Schedule Variance = Predicted Earned Value - BCWS
$$SV_p = EV_p - BCWS$$
<u>or</u>,
$$SV_p = f_3 \text{ (Actual Schedule Variance, Months)}$$
$$SV_p = f_3 (SV_a, M)$$
$$SV_p = B_{sv}M$$

5. Predicted Labor Variance = f_4 (Actual Labor Variance, Months)
$$LV_p = f_4 (LV_a, M)$$
$$LV_p = B_{1v}M$$

Table 6-2. General Equations

1. Coefficients:
$$B_{cv} = 94319$$
$$B_{ev} = 356461$$
$$B_{sv} = 57591$$
$$B_{1v} = 3851$$

2. Predictions and 95% Confidence Intervals

	August 73	November 73	June 74
CV_p	=377276±400053	660234±460061	1320468±664089
EV_p	=1425834±311464	5250081±403047	17067050±1091634
SV_p	=230364±176976	403140±203522	806280±293780
LV_p	=15406±22624	26961±26018	53922±37557

Table 6-3. Results of the Linear Regression

Last, there is a peculiarity in the data due to the difference be-
tween the planned work package budget and the released work package bud-
get (released budgets indi ate that the work package has been opened (or
it is less than two weeks from being opened). Although this is not always
the case, when it occurs it can have a distorting effect on the cost
account numbers, particularly when it is realized that we used a combina-
tion of the two types of work package budgets to get the BCWS numbers
to June 1974. Essentially what happens is that unopened work packages
may be replanned and rebudgeted (within the confines of the appropriate
cost account budgets) up to two weeks before the scheduled opening date.
This has the effect of altering the shape of the cost account cumulative
BCWS curve and hence alters the independent variable in the earned value
regression.

Summary. Despite these drawbacks, this approach or one similar to
it should be better than what is now being done in the A-10 program CPR,
especially for near term predictions (like the 7th month point we used).
It also offers the advantage of being able to look at the problem
functionally if desired, because the data is at the cost account level.

The Gompertz Model

The advisors in the A-10 SPO suggested that the cumulative BCWS
curve might have a distribution similar to that of the Gompertz Curve
which has often been used in the area of technical forecasting (34:113).
The equation for the Gompertz Curve is:

$$Y = Le^{-be^{-kt}}.$$

It ranges from zero at t equals minus infinity to the upper limit, L,

at t equals plus infinity, where t is the independent variable. However, the curve is not symmetrical. The inflection point occurs at $t = (\ln b)/k$, where $Y = L/e$. Figure 6-7 shows a Gompertz Curve for which L, b, and k are all equal to one.
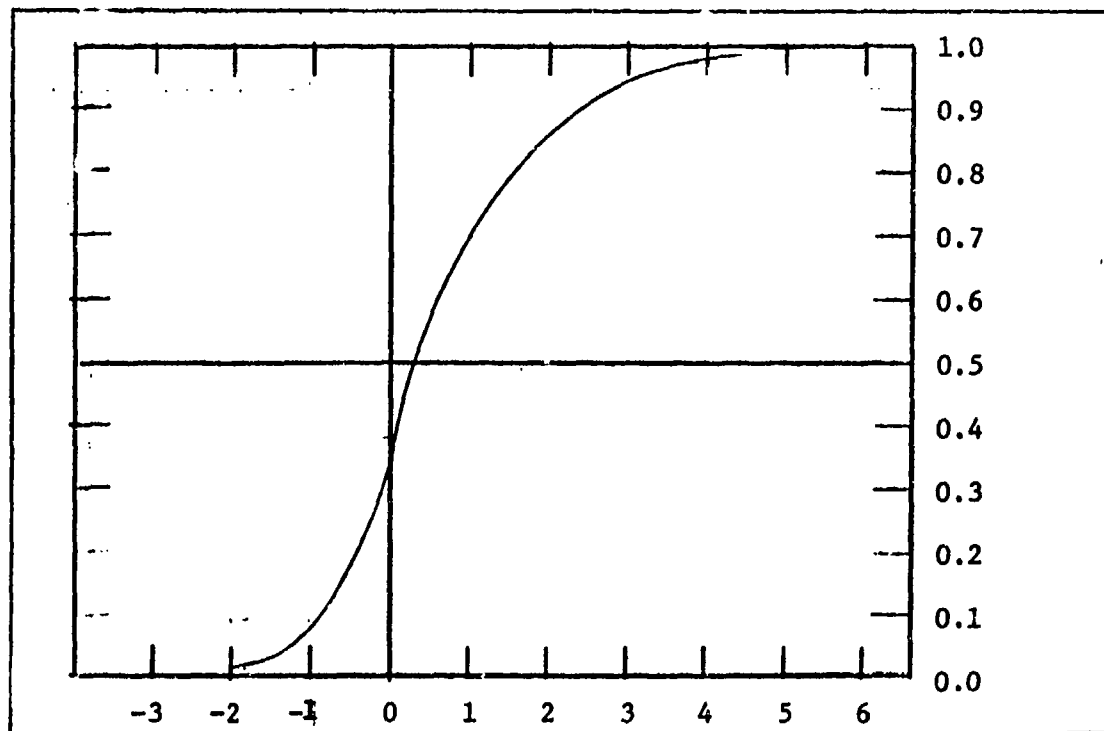
Figure 6-7 Gompertz Curve

Implementation. We used the GROCRV program on the CDC computer to perform the Gompertz regressions (see Appendix E). We first regressed the Gompertz Curve against the projected cumulative BCWS for the total A-10 Development Program. As shown in Figure 6-8, the Gompertz Curve appears to "fit" the cumulative BCWS curve fairly well. The Coefficient of Determination using a L value of 125 million dollars is 0.99834. If one further assumes that the ACWP cumulative curve has a similar shape, then the Gompertz Curve could possibly be used to predict future ACWP values using data from the CPR.
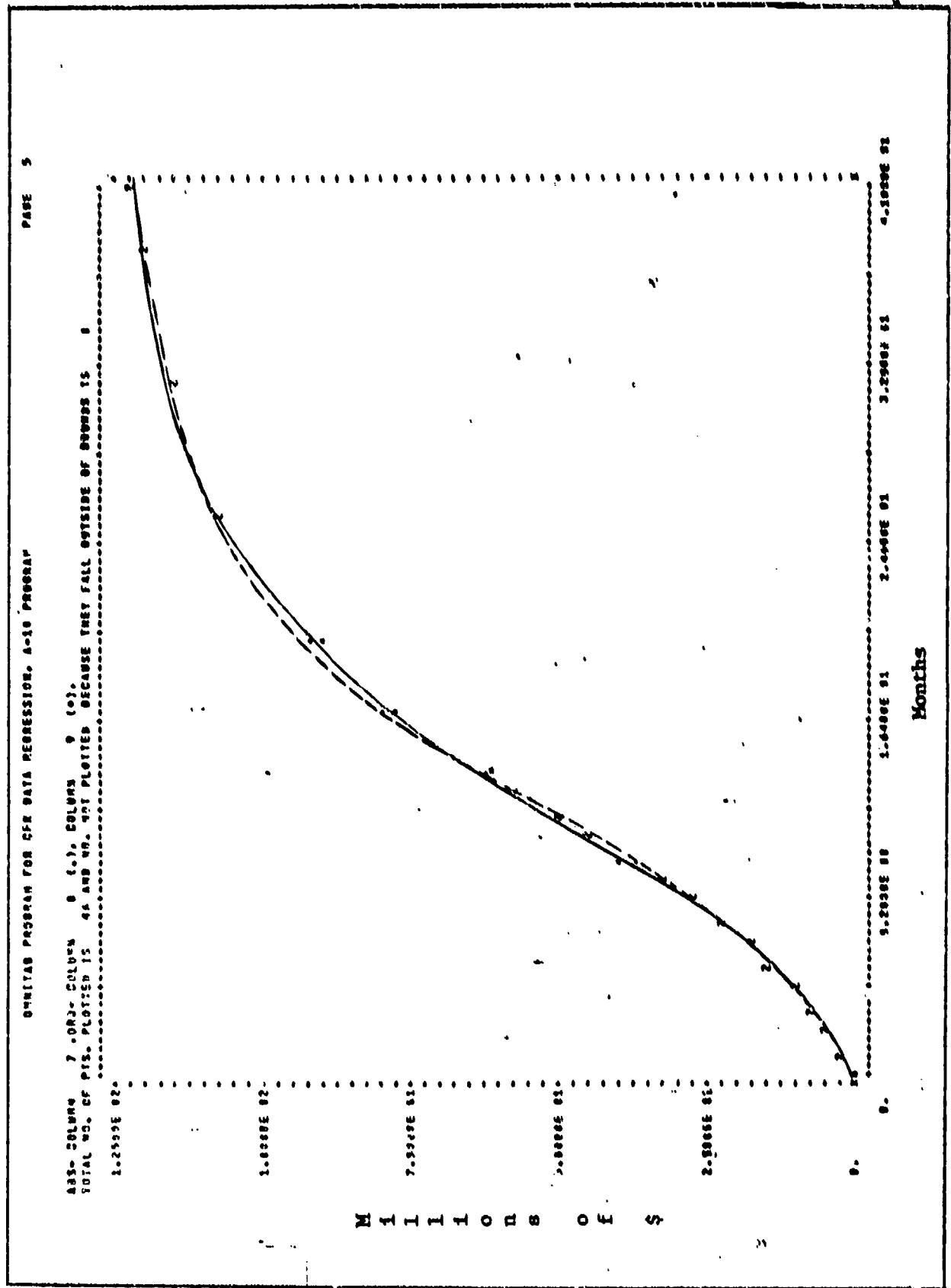
Figure 6-3 BCWS vs. Gompertz Predicted bCWS

As with the linear regression model, only the cumulative accounts from the Basic Structure WBS elements were used. Since the data from the two MCIS reports was suspect, we used CPR data for this effort. The data set included eight months of cumulative ACWP numbers and a range of possible ACWP values for the Estimate at Completion. We used the 38th calendar month as the terminating month since Basic Structures are to be completed by this time. By varying the ACWP values at completion, we constructed a family of predicted curves that might possibly represent the actual dollar expenditures (in millions of dollars) for the Basic Structures element during the program (see Figure 6-9). Fitting the Gompertz curve to these nine points (the eight data points and the estimated end-of-program ACWP) resulted in very high Coefficients of Determination for all the regressions. They ranged from 0.99952 to 0.99965. The upper limit, L, was adjusted through trial and error to obtain the highest Coefficient of Determination for each data set.

Findings. As one can see by looking at Figure 6-9, all the curves are almost superimposed on one another during the early stages of the program. They do not begin to diverge until about the 10th month. At the 12th month the divergence is ample to begin comparing CPR data for that month with the predicted values and determine, possibly, which of the actual cost curves the contractor appears to be on. As the program progresses and additional data becomes available, the curves could be up-dated and some of the outlying curves could be eliminated as infeasible.

The inflection points of the Gompertz curves fitted to the BCWS cumulative data and ACWP data could be compared to provide another means of estimating which actual curve the contractor was following. This could be used as early as the 14th month since the inflection point appears to

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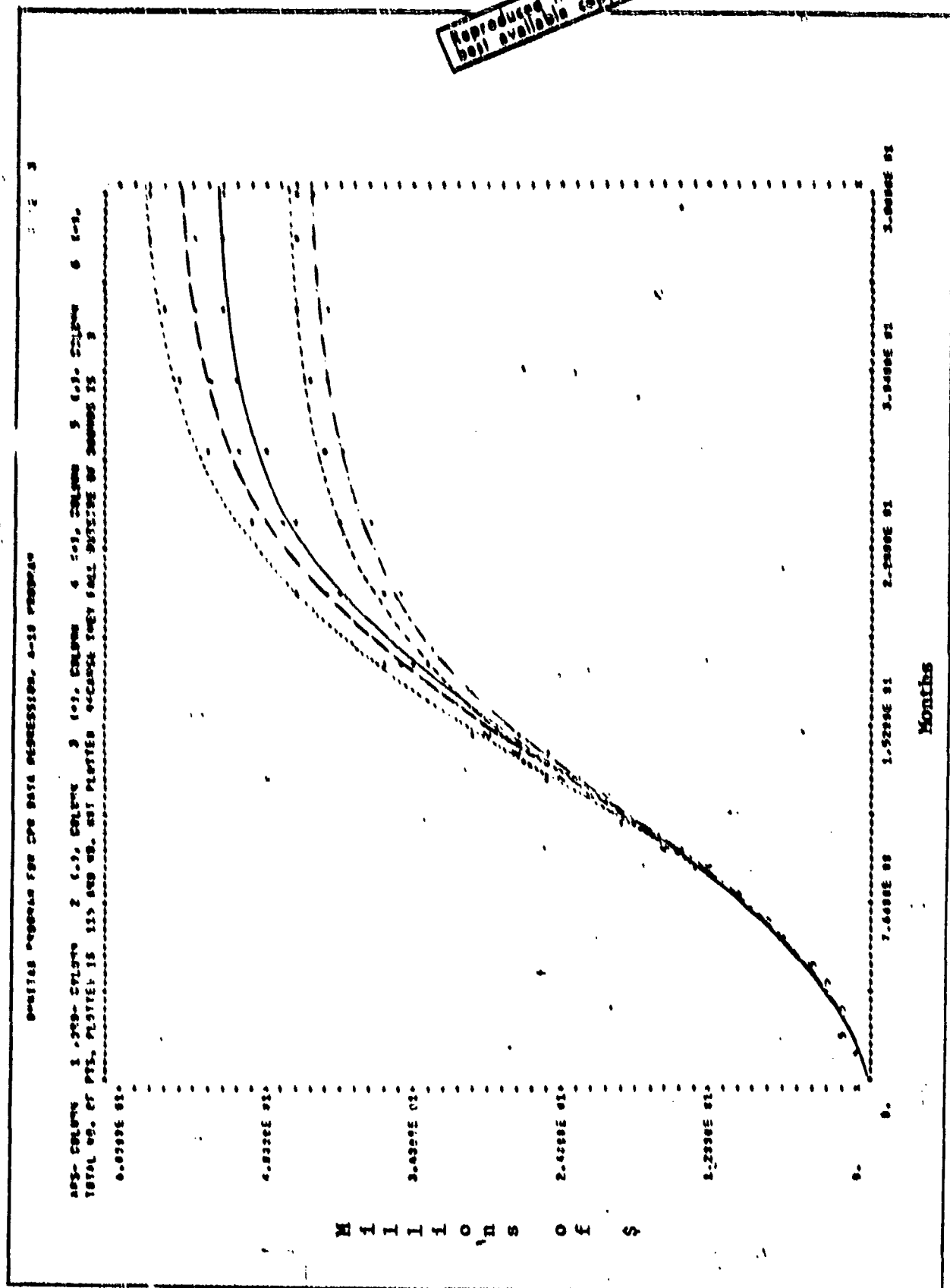
Figure 6-9   Predicted (Gompertz) Cost Curves for Basic Structures

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occur about that time in the program.

Summary. The assumptions necessary for this methodology are shaky at best. Even if the Gompertz Curve does fit the BCWS curve reasonably well, there is no guarantee that the ACWP curve will be similar to the BCWS curve. Problems encountered in the program could cause a rapid shift from one predicted curve to another and even result in multiple inflection points in the actual curve. Such a case can easily occur in the A-10 program because the contract is being renegotiated as a result of funding alterations by Congress.

VII. Conclusions and Recommendations

In the beginning of the study, we thought we had a well bounded problem suitable for a scientific management approach; however, as we learned more about the weapons acquisition process and management within the System Program Office, we discovered that the weapons acquisition process is complex, dynamic, and fraught with many sources of uncertainty. Even though wo were unable to implement the proposed methodology, we feel that the learning process experienced allows us to draw some conclusions concerning the risk assessment approach taken here and to make a few inferences about risk analysis in general in the process of buying weapons. Finally, we have proposed some recommendations which we hope will be of some benefit to others who might contemplate study in this area. We caution that the contents of this chapter are based mostly on our opinions which in turn are the result of a sample size of one, namely the A-10 Full Scale Development Program.

Particular Conclusions and Recommendations

1. Conclusions: Although not a risk assessment in the strict sense of the AF Academy Study Team's definition, the methodology proposed in this study could provide the contractor and government with useful information.

The AF Academy Study imp. les that risk assessment is a component of risk analysis, that is, the first step in risk analysis is to determine the risk associated with each of the possible alternatives. In this case study there was only one basic alternative, that of developing the A-10 aircraft. Also, to be considered a true risk assessment, all three variables, i.e., cost, time, and technical performance, should be assessed to obtain the "program" risk. For reasons explained in Chapter 2, we

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excluded the performance variable. However, we feel that the methodology

could still provide useful cost and schedule information. Its main

attribute is the presentation of cost and time estimates in a probabilistic

format, rather than as point estimates. The manager is provided a range

of possibilities from which implications of uncertainty can be drawn for

each activity, and the total program, by observing the statistical variance

in the resultant distributions.

Since there is only one alternative, the methodology is essentially

an information system. By using the principles of management by exception,

the AF program manager can identify areas with high "estimate" uncertainty

and high probability of not obtaining planned cost and schedule objectives,

and thus devote most of his attention to those areas. However, the

information will not tell him what is wrong. There are three possibilities:

(a) the initial plan was in error (possibly due to target or process

uncertainty), (b) the plan is being poorly executed (internal program

uncertainty can cause this) or, (c) the data is inaccurate (most likely

due to bias in the estimates or, in this case, possibly to the exclusion

of the performance variable). Logically, the manager would seek to

determine the cause or causes. If he then acted to correct those causes,

the methodology could be considered a type of control system. The

implications of this deduction will be discussed later.

Recommendation. If the probabilistic format is considered useful,

then perhaps the Cost Performance Report could be altered to present the

data in this way at substantially less cost than would be incurred using

this network methodology.

2. Conclusion: A technique, like that attempted in this study, which

employs network analysis and subjective probability techniques should

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not be attempted without a strong commitment by both the SPO and the
contractor.

The methodology is very similar to that of PERT, except for the
stochastic treatment of data. Like PERT, the program should be applied
early in a development effort with the full support of those who are
going to use and maintain the system. Otherwise, there may only be
a superficial desire to see the system work, and it may become just
an ancillary, bureaucratic function. As suggested by the AF Academy
Study, it should be implemented by an interdisciplinary team made up
of trained analysts in mathematics, probability, statistics, operations
research, and computer science - aided by cost analysts, production,
design, and engineering people, and experts in various technical disciplines
(33:6). The cost of this approach would be high, but we see no other way
to reliably test its feasibility. Unfortunately we did not have the
time nor the resources necessary to take this normative approach. Further,
neither the contractor nor the SPO was willing to incur the cost of such
an elaborate management tool considering the relative simplicity of the
aircraft to be built.

Recommendation: If both industry and government mutually determine
that this type of methodology has potential merit for an individual
program, then they should commit the necessary resources to insure a
reasonable degree of success. In our opinion, it is doubtful that this
type of methodology can be successfully implemented unilaterally by the
Air Force on a low key, low cost basis.

3. Conclusions: Successful use of this type of methodology as a
control system is unlikely. As indicated in the first conclusion, there
may be a tendency for the Air Force to use the system as a means to

monitor and control contractor performance. Since the input data for
the methodology is obtained subjectively from personnel in the contract-
or's organization, its use as a control system by the AF will most likely
increase the estimate bias as a result of adverse feedback reactions.
These reactions, both intentional and unintentional, may suppress the
flow of accurate information between the contractor and the SPO. Within
his own organization even the contractor may have some difficulty in
getting the experts to accurately transmit their perwactions upward to
their superiors, but at least the contractor has some control over this
internal bias via the infusion of a compensating management philosophy.
If this methodology is used by the SPO to correct contractor performance,
the contractor may be reluctant to provide unfavorable information,
especially in a situation like the A-10 where a company's survival as a
prime contractor may depend on an impending production decision.

Recommendation: If the information from this type of methodology
is to be supplied to the AF program manager, extraordinary measures should
be taken to avoid using the system as a control device, lest it be
rendered useless by adverse feedback reaction.

4. Conclusion: SAIMS in the A-10 program has two major short-
comings: (a) as presently determined, the time variance (given in dollars)
is inaccurate and misleading, and (b) although required in the contract
via the CSCS Criteria, the contractor is not supplying the SPO with
sincere cost variance forecasts.

Recommendation: Determine a more accurate method of calculating
the schedule variance. The methodology proposed here would provide
schedule variance forecasts in some time unit, probably days, but if it
cannot be implemented perhaps a summary event network of critical

milestones could be constructed and used to provic this information. An alternative is to enforce the spirit of the C/SCSC and require the contractor to work the variance estimates up from the work package level. (However we feel that the effort involved in accomplishing this task <u>monthly</u> would not be justified by the information obtained). The estimate reliability and the workload involved could be increased and reduced, respectively, by moving the forecast date from "At Completion" to, say, "Six Month Forecast".

5. <u>Conclusion</u>: Of the two regression models attempted in this study, the Gompertz model appears to give significantly more plausible variance forecasts than does the current CPR. However, due to the inaccuracies inherent in such models, heavy reliance on them would be inappropriate.

<u>Recommendation</u>: The Program Office should follow up on the Gompertz model to assess its accuracy in predicting future cost and schedule variances (in dollars) during the remainder of the A-10 DT&E program.

General <u>Conclusions</u> and <u>Recommendations</u>

1. <u>Conclusion</u>: Within the DOD there is little syntactical convention with regard to the term "risk analysis". In talking to members of other program offices within ASD, we found that "risk analysis" generally infers analysis of what we have called "technical uncertainty".

<u>Recommendation</u>: The definitions concerning risk analysis, risk management, and risk assessment listed in the AF Academy Study should be adopted and incorporated in an appropriate DOD document.

2. <u>Conclusion</u>: We question the requirement for <u>all</u> major development programs to engage in "formal risk analysis". We doubt that "formal" risk management, as required by DOD directives, is appropriate in programs

like the A-10. Compared with other development programs like the B-1 advanced manned bomber and the F-15 air superiority fighter, technical uncertainty in the A-10 program is low. This is primarily due to the previously completed competitive prototype program, where two prototype aircraft were built and tested in an operational-like setting prior to source selection for the DT&E contract. The design to cost criteria enforced engineering tradeoffs that further reduced the "doctrine of quality" environment often blamed as a major cause of contract performance degradation. This is not to say that problems in the A-10 program have not or will not occur, but, in our opinion, the program does not warrant a costly formal risk assessment like that suggested by the AFA Study.

Recommendation: Delete the requirement for all major development programs to employ risk analysis. Prior to the RFP, the SPO should determine, based on a preliminary assessment of program risks and the intended management method, whether, when, how, and to what extent risk analysis should be employed in the program. This could be conducted under some broad DOD guideline, but the actual data requirements for the specific analysis must be included in the RFP.

3. Conclusion: Regardless of the sophistication and elaboration of any scientific methodology used to predict program performance, process uncertainty can invalidate the model and the forecast. The A-10 program is a case in point. Pending Congressional funding alterations may delay production by as much as 12 months, with the associated rise in costs. Externalities like this are difficult, if not impossible, to model in an objective manner.

Recommendation: None

Suggestions for Further Study

The weapons acquisition process is an intriguing yet exasperating area for a formal research. We feel that further study could produce measureable benefits for the DOD and, ultimately, for the taxpayers. We list here a few suggestions for such future efforts.

SAIMS Schedule Variance. Perhaps, with some alterations to the present system, more accurate calendar time variance can be predicted and reported in the Cost Performance Report. A study should be conducted to determine a practical means of doing this.

Technical Performance Measure. To exclude the performance parameter in most R&D programs would be to invalidate the assessment. We feel that technical uncertainty "drives" cost and schedule uncertainties to a large extent. Pl sently, the performance variable is the most difficult to address since it is not homogeneous. Thrust, weight, and turning radius cannot be aggregated into a single "performance" factor. A study should be conducted to develop a transformation algorithm which would yield some type of reasonable performance utile for aggregating these heterogeneous performance elements. Parametric cost estimation would be a logical starting place for such a study.

Formal Risk Analysis. An attempt should be made to implement a formal risk analysis of the type envisioned in this study. A development program with high technical uncertainty should be chosen, and the effort should begin at the conceptual stage, prior to the Request for Proposals. It should continue as long as significant program uncertainties still exist.

Summary

Our ultimate purpose in writing this thesis has been to document

an attempted application of quantitative risk assessment in an on-going
weapons acquisition program. We hope that through our observations and
inferences the reader will gain a better understanding of risk assess-
ment and risk analysis, and their application in the R&D environment.
Perhaps these conclusions and recommendations will provide some insight
and guidance for future researchers who may tread similar paths.

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APPENDIX A

A-10 Program History

Considering time constraints on this study and the lack of a convenient manner for dealing with the non-additive performance variables, the Fairchild Republic Company (FRC) A-10 specialized close air support aircraft program was considered a near ideal test case. From the outset of the study members of the Program Control Division, A-10 System Program Office (SPO) indicated a keen interest and a willingness to assist in any way possible.

The A-10 program is unique in recent weapons acquisition annals. Studies on the need for such an aircraft began in 1967 and culminated in Development Concept Paper (DCP) 23A, which was released 6 April 1970 (16). That DCP outlined the need for an A-X (designation for an attack aircraft in the conceptual phase). Principal requirements for the specialized close air support aircraft were: (a) an integral anti-tank cannon, (b) high payload capacity, (c) small turn radius, and (d) long loiter time.

A Request for Proposals (RFP) was issued 7 May 1970 and six companies responded. Two companies, Fairchild Industries, Fairchild Republic Division, and Northrop Corporation, were chosen to enter the Competitive Prototype Phase (CPP). The prototyping approach had not been used on an aircraft development program since the ill fated North American Aviation B-70 effort. The CPP required each contractor to build two prototype aircraft and submit them to an intense operational prototype competitive flyoff (31:46).

Firm fixed price contracts were let, FRC for $41.2 million and Northrop for $28.9 million (7:14). Authorization for these contracts came from Defense Systems Acquisition and Review Council (DSARC) I. Implicit in the DSARC approval was another salient feature of the

program - a cost bogey of $1.4 million recurring flyaway cost per unit
in 1970 dollars based on a buy of 600 aircraft at 20 per month. The
phrase "design to cost" thus was applied to the program. A Business
Week article headlined " 'Design to cost' is the Pentagon's newest
buzz-phrase".

> The new Pentagon policy is having its sharpest test, however,
> in the final competition between Northrop Corp., and Fairchild
> Industries, Inc., for a contract to produce 600 close air support
> aircraft. Air Force Secretary Robert C. Seamans, Jr., has ruled
> that the average unit production cost of the plane (designated
> the A-X for attack experimental) must not exceed $1.4 million.
> It it does, he warns, there will be no Air Force purchasing
> orders (1:40).

Subsequent to the CPP flyoff, FRC was chosen to receive a cost plus
incentive fee (CPIF) contract to produce 10 development, test, and
evaluation (DT&E) aircraft. Secretary Seamans was the source selection
authority and used a weighted system to make the selection (40:14-15).
The choice coincided with the USAF Source Selection Advisory Committee's
(SSAC) recommendation. The FRC prototype used General Electric (GE)
TF-34 engines identical to ones used in the U.S. Navy S3A antisubmarine
aircraft program but the DT&E proposal included some engine modifications
so two separate Government Furnished Equipment (GFE) contracts were let
to G.E.

The FRC contract was let at a nominal $159.279 million with a
70/30 government/FRC share ratio for costs over the negotiated price.
Two fixed price plus incentive fee (FPIF) contracts were let to GE, one
at $27.666 million for the full scale development of 32 engines, and
the other at $14.892 million for the qualification program. A smaller
competitive prototype program was conducted to name the 30mm anti-tank
gun manufacturer. The competitors were General Electric Co., and Philco-

Ford Corp. The Philco-Ford design failed to perform and GE was given

a third GFE FPIF contract at $23.754 million for the gun development.

The DSARC confirmed that FRC was the CPP winner on 17 January 1973.

Within a week executives of AVCO Corporation, builders of the engine

for the losing Northrop design, protested the award, saying that

pressure by Long Island, N.Y., (location of FRC) businessmen and politi-

cians had influenced the USAF decision (45:22). USAF countered with a

statement to the effect that the AVCO engine did not have the thrust to

power the heavier Fairchild aircraft and Lt. Gen. James Stewart, Commander

of Aeronautical Systems Division (the develop manager) said of the A-10

choice:

> The Fairchild people had their eyes further downstream in the
> company's approach to a prototype model... We can do a great
> deal more with the Fairchild prototype than with the A-9A.
> The prototype-to-production transition will be much better with
> the A-10A (41:17).

Representative George D. Mahon (D-Tex) attempted to delay the

signing of the contract, contending the Texas built Ling Tempco Vought

A-7D attack aircraft would perform the close air support role envisioned

by the Air Force. He was sidestepped when USAF signed the contract on

1 March 1973, even while two Congressional investigations were still

in progress (one by Rep. Mahon and another by Senator Lowell P. Weicker,

Republican from Connecticut, home of AVCO Corp.). That action displeased

Congress and further anti-A-10 sentiment erupted (40:14-15).

In an attempt to appease Rep. Mahon, USAF released to him the results

of a classified computer simulation, Sabre Armor Charlie, which showed

the A-10 to be a superior choice over the A-7D in the scenario envisioned

for the aircraft. Another result of the dissention was a Senate Armed

Services Committee proposal advocating a competitive flyoff between the

A-10 and the A-7. USAF opposed this as both unnecessary and as
infeasible with only the prototype A-10 available. The alternative
of postponing an A-10 production decision until after a DT&E aircraft
(built on production tooling) could be flown against the A-7 was deemed
too expensive and too time consuming. An August 1973 article in
Aviation Week and Space Technology quoted one USAF officer as prefering
a prototype flyoff (albeit without the A-10's primary weapon, the GAU-8
30mm gun) rather than waiting two years for a production configured
aircraft to emerge. That same article further states:

> The thinking reflects a growing opinion in USAF development circles
> that programs should be adequately funded or cut off completely
> at an early stage, rather than the start, go slow, halt, restart
> cost-escalating tendency now prevalent. Primary reasons for the
> trend are constrained Defense Department budget requests and
> subsequent congressional cuts triggered by the current anti-
> military sentiment and past pentagon management bungles (14:17).

Threats of program cancellation by Congress forced USAF to agree
to a flyoff (49:22-23). Senate rules for the flyoff were extremely
vague:

> This flyoff would not have to be too long or complex. The main
> point of the flyoff is to take experienced combat pilots and let
> them fly both airplanes, the A-10 prototype and the A-7D, and
> then make a judgment as to which airplane they would rather fly
> in combat (49:22-23).

Senator Harold Huges (D-Iowa), author of the above quote, had sponsored
a bill to terminate the A-10 contract and the flyoff agreement helped
to defeat that proposal (49:14).

From late September 1973 to this writing, the status of funding
for the A-10 program has vascillated through various Congressional
committees. The most recent activity was to restore $10 million cut
by the Senate and to sustain a $35 million cut in long lead time money,
leaving the program at about $107 million and subject to production

delays should that decision be made.

The impact of such a loss would probably be a reduction from 10 to 6 DT&E aircraft and up to 12 months delay between conclusion of the DT&E pre-production phase and first flight of a production aircraft.

The flyoff will be conducted beginning 15 April 1974 and will use Tactical Air Command pilots as evaluators. Since there is not gun in the number 1 prototype aircraft, there will be no ordnance delivery. Instead, the test will be conducted on an instrumented range at Ft. Riley, Kansas, and telemetry data will be used in reaching a conclusion.

APPENDIX B

Properties of the Triangular Distribution

Surprisingly, we found very little infomation on the non-symetrical triangular distribution. Although the VERT simulation routine is programmed to handle this distribution, we thought it important to derive the properties of the triangular distribution in order to obtain a working knowledge of its use:
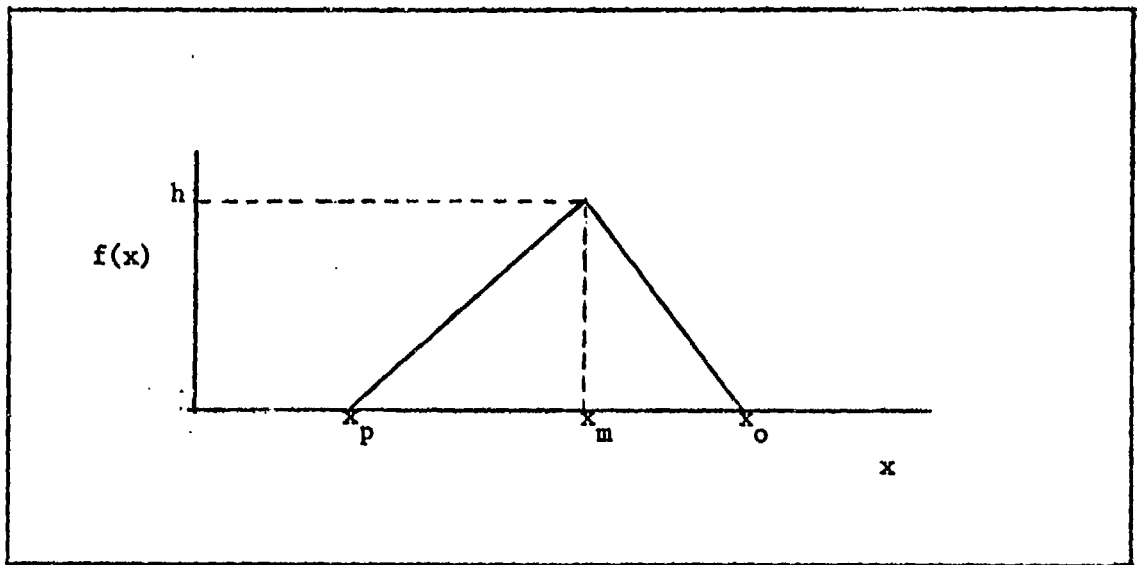
Figure B-1   Triangular Distribution

where x_o = optimistic time

x_m = most likely time

x_p = pessimistic time

Standardizing to zero:

$$b = x_m - x_p$$

$$c = x_o - x_p$$

The area of the triangle = $hc/2$ = 1 since the area under the pdf must equal one. Solving for the height (h):

$$h = 2/c$$

Due to the discontinuity, the pdf is given by two functions:

$$f_1(x) = 2x/bc \ , \ x_p \leq x \leq x_m$$

$$f_2(x) = 2(c-x)/c(c-b) \ , \ x_m \leq x \leq x_o$$

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The expected value is given by: $\int_{-\infty}^{+\infty} xf(x)dx$, therefore:

$$E(x) = \int_0^b 2x^2/bc \ dx + \int_b^c 2(c-x)x/c(c-b) \ dx$$

$$= c+b/3$$

The variance is given by $V(x) = E(x^2) - [E(x)]^2$ with the following results:

$$V(x) = c^2 - 3cb + b^2/18$$

The cummulative distribution is also in two parts with:

$$F_1(x) = x^2/bc \ , \ x_p \leq x \leq x_m$$

$$F_2(x) = [b(b-2c)x(2c-x)]/c(c-b)+b/c \ , \ x_m \leq x \leq x_o$$

In order to employ Monte Carlo techniques, the inverse relationship, $x = G^{-1}(y)$, must be formed:

$$x = \sqrt{ybc} + x_p \ , \ 0 \leq y \leq b/c$$

$$x = c - \sqrt{c^2(1-y) - bc(1-y)} + x_p \ , \ b/c \leq y \leq 1$$

APPENDIX C

Description of VERT

[Extracted from Bevelhymer (10)]

A. Description of VERT Process

VERT is a network tool which utilizes simulatio. as a means of deriving solutions. It has an extensive array of logical and mathematical features which makes it possible to analyze complex systems and problems in a less inductive manner than traditional methods. When using this tool, the user can expend more time on individual component time, cost, and performance analysis rather than developing the interaction among components. The extensive number of operands available removes the inductive headaches from modeling component interaction. These operands enable the user to explore conditional nonlinear multivariate situations which defy ready mathematical analysis. VERT enables the user to create a fourth dimension, "risk," which is used as a common measure to integrate the three principal dimensions of time, cost, and performance. Risk is the endogenous variable being controlled by the exogenous variables time, cost, and performance.

VERT has two parts. Part one consists of constructing a graphic network representation of the project. Part two consists of analyzing that network through the use of a computer program.

Figure C-1 is an example graphical network representation depicting elemental activities, events, and real time decisions. Real time in this context has the following connotation: the decisions made within this mathematical simulated network would be the same as those the manager on the job would make, given the time, cost, and performance values derived by the network for each of the various decision alternatives provided to be the same as those encountered in the actual project development.
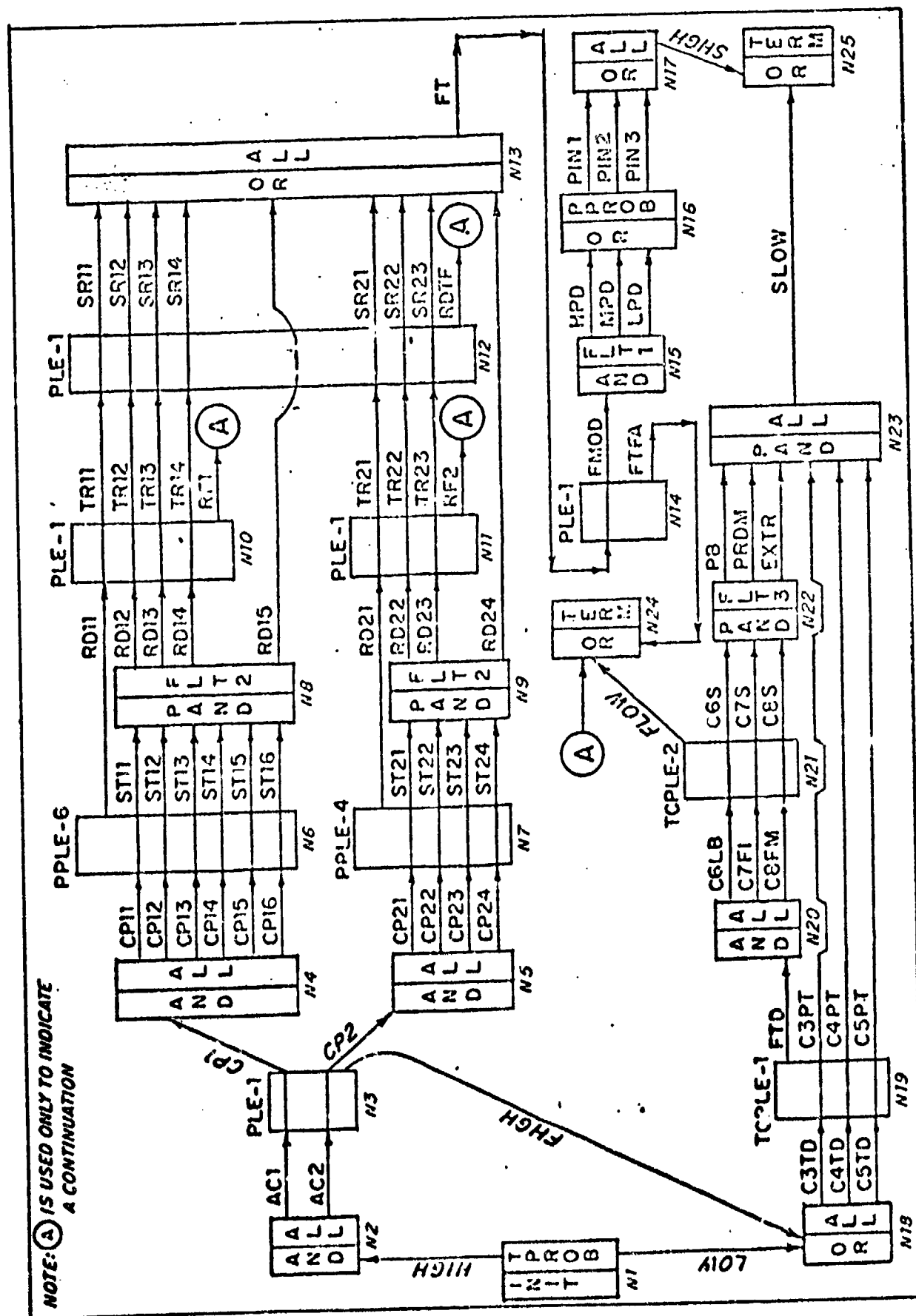
Figure C-1. Armored Reconnaissance Scout Vehicle

In the VERT system, project activities are represented by arcs, and events or milestones are represented by nodes. The arcs and especially the nodes are used to create the real time decision capability. Therefore, the flexibility and array of capabilities structured in the nodes and arcs become a very critical consideration when attempting to model an unusual decision situation. The guideline followed in designing VERT is that of trying to strike a balance between having enough features available to efficiently model any decision situation versus over burdening the user with features to the point that only technicians can cope with this tool.

While pictorially describing the project in terms of the VERT operands, numerical values for time, cost, performance, achievement and event probabilities are assigned to the various project elements. Procedures useful for eliciting data have been suggested by Dalkey (1970), Northrop (1970), and Raiffa (1970). The numerical values assigned must be measured in a consistent number throughout the network. Time cannot be specified in terms of weeks in one section of the network and in terms of years elsewhere. Likewise, cost must be measured in identical units as ten, hundred, or thousand dollars, etc., throughout the network. Performance can be expressed in terms of any meaningful index such as horsepower, weight, reliability, utiles, return on investment, quality appraisal, systems worth, etc.

Time, cost, and performance for each activity can be jointly or singularly modeled as a functional relationship with other node or arc time, cost and performance parameters in the network and as a stochastic variable. This dual capability enables modeling the functional relationship portion of a regression equation among key parameters in

the network and additionally modeling the stochastic residual. VERT
has the following 14 transformations to aid in the task of expressing
functional relationships among the key parameters.

No.	Transformation	No.	Transformation
1	$C_1 X_1 \rightarrow X_2$	9	$C_1 [Log_{10}(C_2 X_1)] \rightarrow X_2$
2	$C_1 / X_1 \rightarrow X_2$	10	$C_1 [Sin(C_2 X_1)] \rightarrow X_2$
3	$C_1 (X_1 + C_2) \rightarrow X_2$	11	$C_1 [Cos(C_2 X_1)] \rightarrow X_2$
4	$C_1 (X_1 - C_2) \rightarrow X_2$	12	$C_1 [Arctan(C_2 X_1)] \rightarrow X_2$
5	$C_1 (X_1^{C_2}) \rightarrow X_2$	13	$X_1 \geq C_2 : C_1 X_1 \rightarrow X_2$ otherwise $C_1 C_2 \rightarrow X_2$
6	$C_1 (C_2^{X_1}) \rightarrow X_2$	14	$X_1 \geq C_2 : C_1 C_2 \rightarrow X_2$ otherwise $C_1 X_1 \rightarrow X_2$
7	$C_1 (e^{C_2 X_1}) \rightarrow X_2$		
8	$C_1 [Log_e(C_2 X_1)] \rightarrow X_2$		

X_1 represents a time, cost, or performance value previously
derived within the network. C_1 and C_2 are inputted constants. C_1 is
an ordinary multiplier of the transformed variable while C_2 is used to
transform X_1 to X_2.

The functional modeling available in VERT will enable deriving
time, cost, and performance values for each activity as a function of
the following: (i.e., X_1 can be any of the following previously derived
values) (1) node (event) time, cost, performance values (2) arc

(activity) time, cost, performance values. (A parameter must
not be dependent upon itself and there must be a dependency hier-
archy established among these three principal parameters if time
and/or cost and/or performance are interrelated for a given activity.)
To aid stochastic modeling, VERT has 10 statistical distribution input
options which are as follows: (1) constant, (2) uniform, (3) normal,
(4) triangular, (5) erlang, (6) lognormal, (7) poisson, (8) gamma,
(9) beta--3 or 4 parameters, or (10) any distribution, entered as a
histogram approximation to the probability density function.

The degree or extent a project needs to be segmented into
activities and events is a function of available data and the results
desired. Some managers prefer to estimate parameters for entire
modules or higher level work packages, rather than estimating
parameters for the smaller elemental items in those work packages.
Problem size sometimes has a bearing on the way the network is
structured. If a problem is large, it is often advisable to construct
lower level networks (subnets) of major modules. The histogram
inputting capability for an activity's time, cost, and performance
enables stochastic substitution of results from lower level subnetworks
into a higher level network.

Part two of the VERT procedure consists of analyzing the
network through the use of the computer program (Moeller, 1972).
Networks are constructed so that various combinations of alternative
activities could occur to make a project successful. The computer
program explores alternate ways of completing the project through
the technique of simulation. Upon simulating the network a sufficient
number of times, the computer program prints out the following node

time, cost (discounted, if desired), and performance information:

    1. Pictorial histogram approximations to the marginal probability density functions.

    2. Pictorial histograms approximations to the marginal cumulative density functions (see Figure F-1, cell data are printed on the page following the histogram printouts).

    3. Mean observations.

    4. Standard deviations.

    5. Coefficients of variation.

This information is displayed for all internal nodes, intervals between nodes, and terminal nodes as requested. In addition, all terminal node time, cost, and performance data are combined to give a composite terminal node time, cost, and performance printout.

The histogram printout of the probability density function provides a picture of the range and concentration of time, cost, and performance values. Probability of exceeding certain value levels can be obtained from the histogram printout of the cumulative density function. The mean indicates the center of the distribution while the standard deviation gives an indication of the overall spread of the distribution. Lastly, the coefficient of variation enables an inference to be made on the spread of the distribution in relation to its mean.

VERT prints out a bar graph of terminal node utilization (similar to Figure C-2). It is through the use of this printout that the project "risk" can be ascertained. The usual form a decision risk analysis network takes is that of having one or several terminal nodes collect successful project completions, and one or several
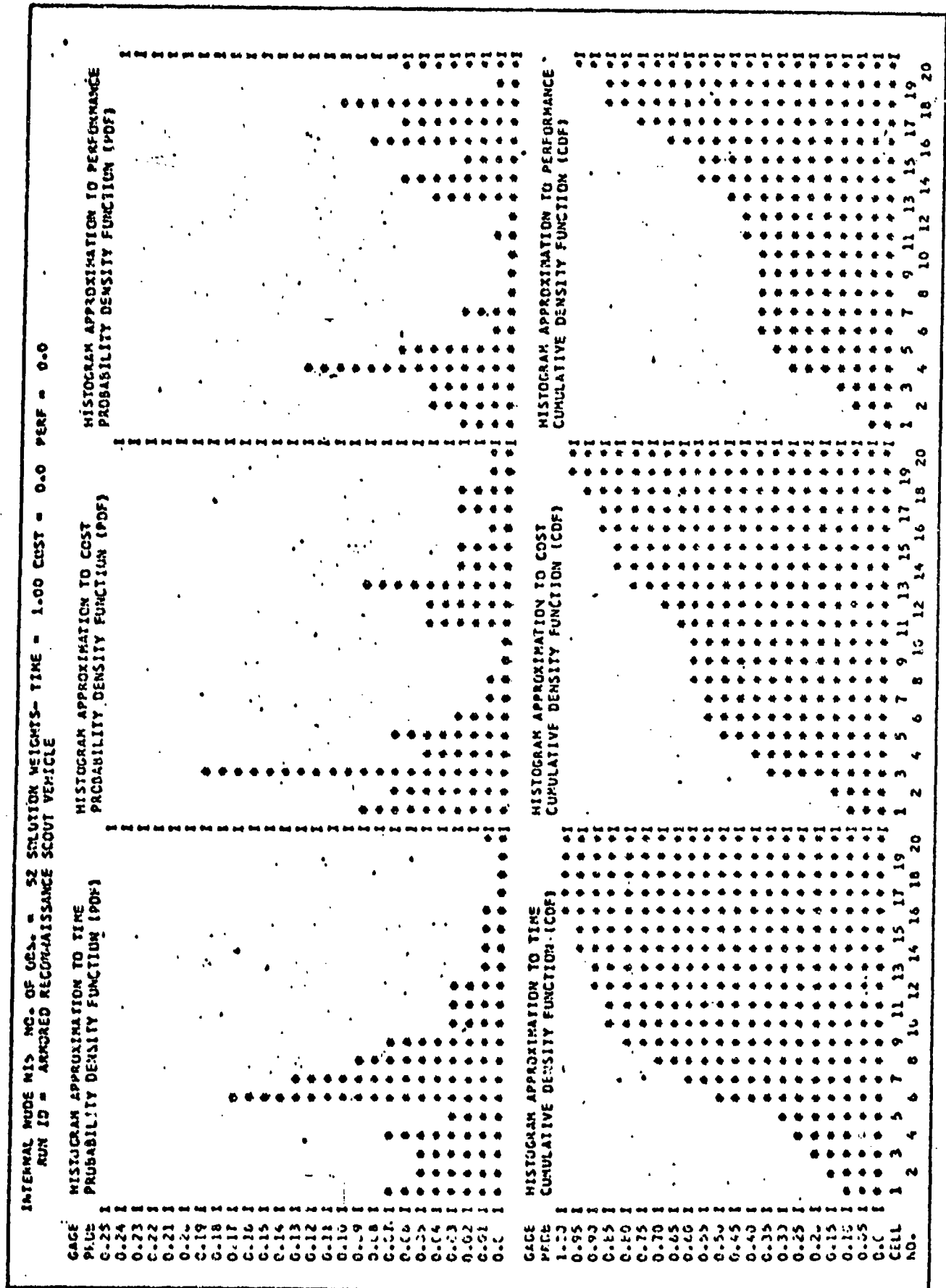
Figure G-2   Armored Reconnaissance Scout Vehicle

terminal nodes collect unsuccessful project completions. Realization of these various terminal nodes compared to the total number of iterations gives an indication of project success or failure. The program next prints out a critical path index for nodes (see Figure F-2) and arcs (similar to Figure C-3). Since different stochastic paths can be realized in the process of simulating the network, the critical path tends to change. Accordingly, the program computes the proportion of time each arc and node is on the critical path. These critical path options facilitate making sensitivity and crash program analysis.

B. Mechanics of the VERT Process

1. General Processing Steps

The processing steps of this program are highly influenced by the various states the arcs assume during an actual simulation iteration. These states are as follows: (1) uninitiated, (2) logically eliminated--will not be considered as a feasible activity for this iteration, (3) unsuccessfully completed, (4) successfully completed, and (5) candidate for the critical path.

An approximate sequence (exceptions discussed in Section I-B-2) of the steps the program takes in deriving a solution for a single simulation iteration is as follows: First, all initial nodes are processed in the order they were inputted to the program. The output logic of these nodes selects certain output arcs for processing and the remaining outputs arcs, if any, are given a status of logical elimination. Whenever an output arc is selected for processing, it is immediately Monte Carlo processed to determine its success/failure status. Time, cost and performance values are also derived for this arc via the functional relationships and/or statistical distri-

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Figure C-3. Armored Reconnaissance Scout Vehicle

bution inputted for it. Next, all the remaining nodes are reviewed in the order they were inputted into the program and all candidate nodes' (those nodes in the immediate area of the network flow) input arcs are checked to see if they have been processed. If these arcs have been processed; time, cost, and performance values for these nodes are derived via the input logic rules discussed in the next section of this paper (Section I-B-2). The output logic for this node selects arcs for processing and/or gives them a scatus of logical elimination. All nonprocessed nodes are continually reviewed until they all have been processed. The optimum terminal node is next determined as the one with the shortest completion time, lowest cost, or highest perform- ance, or the best weighted combination of these three principal factors. VERT provides the capability to partially or fully cost the activities which were initiated before but not completed by the time the optimum terminal node was realized. If time, cost and performance data dis- plays for internal nodes were requested, the program now stores the necessary items needed to complete these displays. The critical path is next determined and stored as the path with the longest completion time, highest cost, lowest performance, or the least desirable weighted combination of these factors. VERT enables optional suppression of critical paths originating from certain terminal nodes. The program then continues on to the next ieration repeating the preceding steps.

To increase the simulation processing speed as much as possible, nodes should be inputted into the program so that any given node causes the processing of input arcs to nodes inputted after the given node. If this task is successfully accomplished, the program will need to review all the nodes only once for each

simulation iteration.

2. Operands

The basic building blocks (operands) of VERT are
nodes and arcs. They are the vehicles used to express the unique
aspects of a project. Their functional relationships are so inter-
dependent that it is nearly impossible to describe the functions of
one without describing some aspects of the other. Arcs perform
two tasks in the network. Their primary task is that of representing
project activities, and their secondary task is that of performing a
logic function within the network. When an arc is used in this latter
capacity only, it is referred to as a transportation arc. Every arc
in the VERT system is characterized by the following:

        a. An arc name

        b. The name of its input node

        c. The name of its output node

        d. Probability of arc completion

Transportation arcs require specification of only the
preceding four attributes, while arcs representing actual activities
require some of the following items:

        e. Separate equations (structured via the trans-
formations built in VERT) for activity time, cost, and performance. .

        f. Stochastic variates for time, cost, and per-
formance.

Nodes having Filter #1, #2, or #3, and time/cost/
performance probability output logic, which are later discussed,
require output arcs to carry the following additional information:

        g. Filter #1 - upper and lower limits on time
and/or cost and/or performance.

h. Filter #2 - upper and lower limits on the number of successfully completed input arcs.

i. Filter #3 - names of other arcs accompanied by an indicator.

j. Time/cost/performance output logic-probability distribution(s) possibly requiring time/cost/performance boundaries.

There are four basic input logics available for the split-logic nodes. These logics are defined as follows:
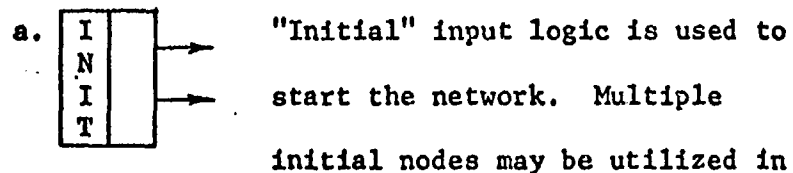
a. "Initial" input logic is used to start the network. Multiple initial nodes may be utilized in a network. Time, cost, and performance values assigned are zero.

If the input logic for the following nodes is not satis-field, all output arcs will be logically eliminated.
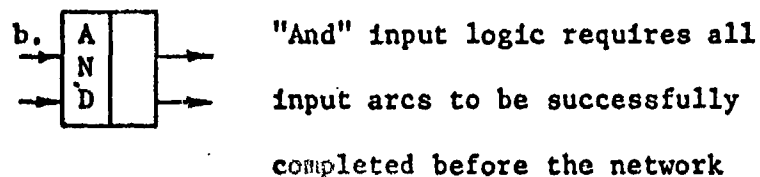
b. "And" input logic requires all input arcs to be successfully completed before the network flow can continue through this use. The time value assigned to this node is the maximum path time of all the input arcs. Cost and performance values assigned to this node are computed as the sum of all the respective path costs and performances of each input arc.
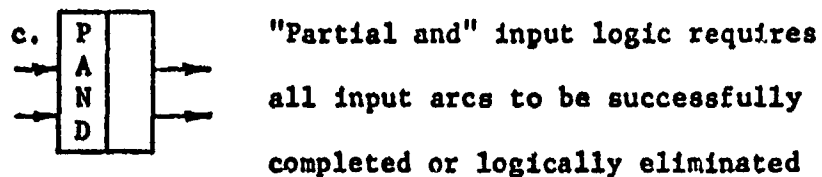
c. "Partial and" input logic requires all input arcs to be successfully completed or logically eliminated from the network. If at least one input arc has been successfully completed, network flow will be allowed to continue through this

node. The time value assigned to this node is the maximum path time of all the successfully completed input arcs. Cost and performance values assigned to this node are computed as the sum of all the respective path costs and performances of each of the successfully completed input arcs.
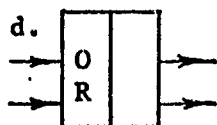
d. "Or" input logic requires all input arcs to be successfully completed or logically eliminated from the network. If at least one input arc has been successfully completed, network flow will be allowed to continue through this node. The time and performance values assigned to this node are the path time and performance values carried by the input arc having the minimum path time. The sum of all the path costs of each of the successfully completed input arcs is the cost value assigned to this node. Arcs flowing directly and indirectly into an OR input logic node having input node completion times greater than the completion time of this OR node will be pruned from the network via being given a status of logical elimination from the network. If an arc is pruned from the network in this fashion, the network flow will be restarted from this pruned arc. Restarting the network flow will reprocess arcs branching away from the flow into this OR node which have been erroneously processed as a result of this unfortunate processing position of the OR input logic node.

The following six output logics available for split logic nodes will be utilized only when the input logic can be successfully executed.
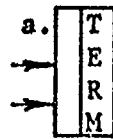
a. | T E R M | "Terminal" – This logic is used to end the network.
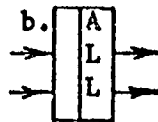
b. | A L L | "All" – This logic will simultaneously begin the processing of all output

arcs emanating from this node.
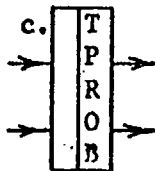
c. | T P R O B | "Time Probabilistic"
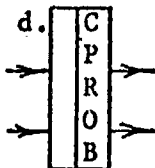
d. | C P R O B | "Cost Probabilistic"
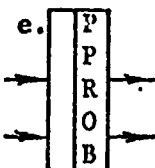
e. | P P R O B | "Performance Probabilistic"

Each of the three preceding logics will start processing only one output arc. Arc processing is accomplished on a probabilistic Monte Carlo basis and can inclu'- - time/cost/performance consideration if desired. The probability-time/cost/performance dependency situation enables inputting three different sets of output probabilities of process initiation separated by two time/cost/performance boundaries. These boundaries create three regions where the three probability sets apply. If the time/cost/performance computed for the node lies between zero and time/cost/performance boundary one, the appropriate time/cost/performance domain is region 1. Probability set number 1 will be utilized in this case. Likewise, if the node time/cost/performance lies between time/cost/performance boundaries 1 and 2, the appropriate time/cost/performance domain

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is region 2 and probability set number 2 will be utilized. Lastly, if the node time/cost/performance lies beyond the time/cost/performance boundary number 2, the appropriate time/cost/performance domain is region 3; probability set number 3 will be utilized.

If time/cost/performance conditioning is not required, only probability set #1 needs to be specified (any of the preceding three nodes [c., d., or e] can be utilized in this particular case). Likewise, if it is deemed that two probability sets separated by one time/cost/performance boundary fit the situation, a single time/cost/performance boundary point and probability sets #1 and #2 need to be inputted. The probability-time/cost/performance dependency capability is utilized in situations where the chances of certain activities being initiated depends upon the time/cost/performance realized at key milestones within the network.
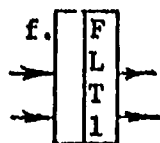
f. "Filter #1" output logic will initiate the processing of one or a multiple number of output arcs. The criteria for process initiating output arcs is based on jointly or singularly satisfying time, cost, and performance constraints placed on arcs emanating from this node. These constraints consist of upper and lower time and/or cost and/or performance boundaries. If the node time and/or cost and/or performance lies within the constraints placed on a given output arc, that arc will be initiated for processing. Otherwise, the arc will be logically eliminated from the network. N-1 of the N output arcs must have constraints placed on them. The Nth output arc must be entirely free of any constraints. This arc functions as an escape arc in the event the constraints of the other output arcs

have been violated. The escape arc will be logically eliminated from
the network if at least one constrained output arc was processed.
Boundaries for the constrained output arcs can be (1) overlapping,
(2) continuous, or (3) noncontinuous, i.e., having gaps. This node
can be processed with one, two, or three constraints simultaneously
being employed. Most large-scale projects have time, cost, and
performance constraints which should be observed. It is appropriate
to use this logic to filter off those simulation interations which do
not fall within the limits of the time and/or cost and/or performance
constraints.

g. "Filter #2" output logic is nearly
the same as FLT 1 except for the
following factors: (1) Only one
constraint rather than one to three constraints can be placed on the
output arcs. This constraint consists of an upper and lower bounds
on the number of input arcs realized by this node; and (2) only PAND
input logic may be employed with FLT 2 output logic. FLT 2 output
logic is useful in constructing testing situations.
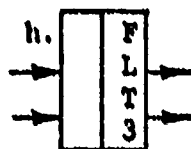
h. "Filter #3" output logic will initiate
for processing one or a multiple
number of output arcs. The cri-
terion for process initiation of a given output arc is based on jointly
satisfying all the arc completion constraints placed on it. Otherwise,
the arc will be logically eliminated from the network. These con-
straints are specified by listing the names of arcs functioning as
constraints and attaching a plus or a minus sign to those names. If
a plus is attached to the arc nmame, this constraining arc must have

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been successfully completed before the output arc being constrained
can be initiated. If a minus is attached to the arc name, this con-
straining arc must have been unsuccessfully processed or logically
eliminated from the network before the output arc being constrained
can be initiated. N-1 of the N output arcs to this node must have
at least 1 and can have up to 15 arc completion constraints placed
on them. The Nth output arc is an escape arc which will be initiated
only in the event the other N-1 arcs fail to be processed. The escape
arc will be logically eliminated from the network if one or more con-
strained output arcs are processed. This output logic is especially
useful for situations where successful completion of prior activities
or the failure of prior activities requires the initiation of other activ-
ities positioned farther on in the network.

For the preceding split logic nodes, the path time, cost,
and performance values assigned to the output arcs consists of the
sum of the individual time, cost, and performance values derived
for those activities plus the time, cost, and performance values
assigned to the arc's input node.

There are four special nodes having unit logic rather than
having separate input and output logic. They require an indication of
how many output arcs are desired to be processed. This number is
indicated in actual network drawings where the pound sign appears
in the small pictorials accompanying these definitions.
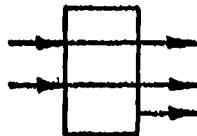
    a. TCPLE-#   "Time Cost Performance Link Escape"
node has N input arcs coupling with
one particular output arc.

Additionally there must be one uncoupled output arc. This arc plays

a role comparable to the role played by the escape arcs in the previous-
ly defined filter output logic.

The number of output arcs initiated for processing de-
pends upon how many input arcs were successfully completed and
on how many output arcs were desired to be processed. One or all
or a subset of all the linked output arcs may be initiated for process-
ing. If there are more successfully completed input arcs than there
are output arc process initialization requests, the following selection
logic is utilized. Those output arcs will be processed whose corre-
sponding input arcs form an optimal subset. Optimal subset selection
can be based on minimum total path time, cost, or maximum path
performance, or the least weighted combination of these three factors.
The remaining output arcs will be logically eliminated from the network.

The time value assigned to this node is the maximum time
value required by the most time consuming arc in the optimum input
arc subset if time is used as the only decision criterion. The same
pruning logic will be employed by this node as is utilized by the OR
input logic node (see last paragraph of OR logic description). If
another decision criterion is used to select the optimum input arc
subset, the node time value is recorded as the maximum time value
of all input arcs which have not been logically eliminated from the
network. The cost value assigned to this node is computed as the
sum of the cost values of all input arcs that have not been logically
eliminated from the network. The performance value assigned to
this node is computed as the average of all input arcs in the optimal
input arc subset.

If the output arc processing request cannot be fulfilled

entirely, all output arcs will be logically eliminated from the network except the escape arc which will then be processed.

If the escape arc is processed, the time value assigned to this node is the maximum time value of all input arcs which have not been logically eliminated from the network. The value assigned to node performance is zero.

b. PTCPLE-# "Partial Time Cost Performance Link Escape" logic is the same as TCPLE logic except that the number
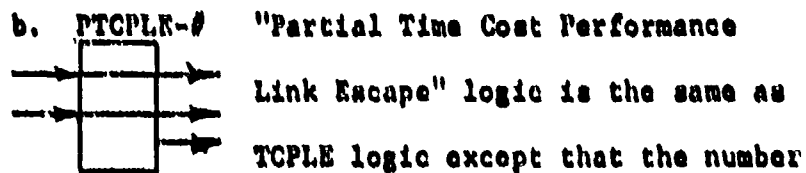
of output arcs processing request need not be fulfilled entirely. If at least one input arc has been successfully completed, the corresponding output arc which links with this successfully completed input arc will be processed. The escape arc will only be processed when all input arcs to this node fail to be successfully completed.

c. PLE-# "Preferred Link Escape" has the same physical makeup as the TCPLE node. The only difference between
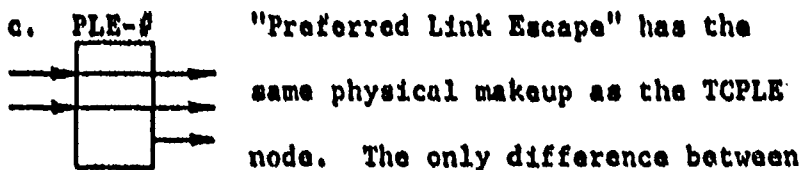
these two nodes is the logic used to select an output for processing. The logic in PLE requires that the first input arc be given preference over the second and the second be given preference over the third, etc. Thus, the criterion for selection is preference, not time, cost, or performance.

d. PPLE-# "Partial Preferred Link Escape" Logic is analagous to PLE as PTCPLE is analagous to TCPLE. (The number
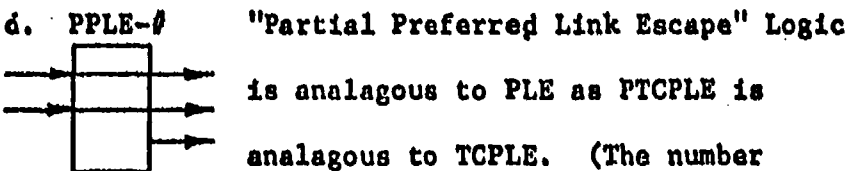
of output arcs processing request need not be fulfilled entirely.)

For the preceding special nodes, the path time, cost, and performance values assigned to output arcs are computed as the sum of the individual time, cost, and performance values derived for those arcs plus the path time, cost, and performance values derived for those linked input arcs. The escape arc is an exception to this rule. Its time and cost value is computed as the sum of the time and cost values derived for this arc plus the time and cost values assigned to the input node. Path performance value for this arc is computed as the individual performance value derived for this arc.

These four nodes are especially useful for structuring major command or board of director type decisions. Since these nodes are the only ones which can accommodate input arcs having probabilities of completion less than one, they are also often utilized as network flow continuity devices. In this capacity these nodes prevent the network flow from dying within the network.

APPENDIX D

OMNITAB Program for Least Squares Predictions

OMNITAB PROGRAM FOR A-10 COST ACCOUNT VARIANCE REGRESSIONS

LIST OF COMMANDS, DATA AND DIAGNOSTICS

```
SCAN 72 $
DIMENSION 83 ROWS X 140 COLUMNS
HEAD 82/SCHED VAR
HEAD 83/COST VAR
HEAD 84/LABOR HR VAR
HEAD 88/COEFF & SD'S
HEAD 89/RESIDUALS
HEAD 90/PRED VAL'S
HEAD 71/BCWS
HEAD 72/BCWP
HEAD 73/ACTUAL DOLRS
HEAD 74/BUDG HOURS
HEAD 75/ACTUAL HOURS
HEAD 78/MONTHS
HEAD 79/SCHED VAR'CE
HEAD 80/COST VAR'CE
HEAD 81/LAB VARIANCE
HEAD 1/DESIGN
HEAD 6/TOOL PLAN'NG
HEAD 11/TOOL DESIGN
HEAD 16/TOOL FABRI'N
HEAD 21/QUAL ASSUR
HEAD 26/PROCUREMENT
HEAD 31/LOFTING
HEAD 36/REPROD'N
HEAD 41/MATERIEL
HEAD 46/HADERS TOOL
HEAD 51/HADERS QA
HEAD 56/HADERS SUP'T
HEAD 61/SUBSYST DESN
HEAD 71/WBS BCWS
HEAD 72/WBS BCWP
HEAD 73/WBS ACTUAL
HEAD 74/WBS SCH LAB
HEAD 75/WBS ACT LAB
HEAD 135/BCWS MAY-JUN
HEAD 136/PRED CST VAR .
HEAD 137/EARNED VALUE
HEAD 139/BCWP+CST VAR
SET 78
1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20
SET COL 1
62600  103819  192794  367333  562132  580413  645574  19089  42020
53032  69399  103848  138607  178486  27735  46849  62479  84881
110897  125934  159885  48341  76549  120138  146414  244967
324798  393778
SET 29 1
19884  36405  53080  69315  116677  139705  168135
SET COL 2
62599  99047  173818  294932  491659  564559  645812
```

OMNITAB PROGRAM FOR A-10 COST ACCOUNT VARIANCE REGRESSIONS

LIST OF COMMANDS, DATA AND DIAGNOSTICS

```
1089339 2444365 2912889 3379170 3679731 4139235
4139235 65854 173249 334972 638843 878231 1092379 1289740
26740 41073 66423 61044 84268 87288 90394
445166 729415 1027858 1331960 1664207 1894693 2039732
3158 24099 28045 28045 28045 28045 28045
SET 36 106
121580 168629 213678 274487 309416 329254 351377
SET 36 109
0 0 0 489820 489820 1024551 1024551
SET 112
299641 347660 354009 380557 393887 406982 415961
59887 77209 80096 91638 96970 98841 101085
32018 54067 66348 74428 77093 79525 82213
66025 97883 120691 146087 163856 176951 187054
17716 31222 38240 42857 46411 49217 51461
93522 117734 125497 136231 144090 151824 160883
SET 36 115
173595 196252 218635 242942 242942 242942 322463
SET 36 118
493350 575304 575304 575304 575304 575304 575304
SET 121
90671 90671 90671 90671 90671 90671 90671
29172 50475 81821 103291 121342 133111 135838
245208 289471 311581 332290 430285 453241 460198
390467 447108 450350 457045 471434 473885 476336
306597 374224 382047 400610 511533 554807 554807
43150 71550 109760 147280 172580 190080 193850
SET 36 124
38438 48471 53452 77906 94103 104940 107239
SET 36 127
106746 115933 123845 131758 134397 136670 139229
SET 22 130
82189 94534 109965 125397 142054 142054 158711
1/ MADD MATRIX IN 1,1 SZ 42X5 TO 1,71 SZ 42X5 PUT IN 1,71
2/ INCREMENT 1 BY 0 5 0 0 0 0 0 0 0 0
PERFORM 1 THRU 2 13 TIMES
NEW PAGE
NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
NOTE    WBS TOTALS ARE IN A 42X5 MATRIX LOCATED AT 1,71
NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
FIXED 0
PRINT 71 ••• 75
NEW PAGE
2.1/ MADD 1,71 SZ 7X5 TO 43,71 PUT IN 43,71
2.2/ INCREMENT 2.1 BY 7 0 0 0 0 0 0 0
PERFORM 2.1 THRU 2.2 , 6 TIMES
4/ MADD MATRIX IN 1,1 SZ 7X65 TO 43,1 SZ 7X65, PUT IN 43,1
5/ INCREMENT 4 BY 7 0 0 0 0 0 0 0 0 0
PERFORM 4 THRU 5, 6 TIMES
NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
```

OMNITAB PROGRAM FOR A-10 COST ACCOUNT VARIANCE REGRESSIONS

LIST OF COMMANDS, DATA AND DIAGNOSTICS

```
    NOTE    FUNCTIONAL TOTALS ARE STORED IN A 7X65 MATRIX AT 43.1 .....
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    SPACE 5
    5.1/ MADD 43.1 SZ 7X5 TO 50,71 PUT IN 50,71
    5.2/ INCREMENT 5.1 BY 0 5 0 0 0 0 0 0
    MPRINT 43.1 SIZE 7X65
    NEW PAGE
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    NOTE    WBS BASIC STRUCTURE TOTALS ARE IN 7X5 MATRIX AT 43,71 ........
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    SPACE 3
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    NOTE    FUNCTIONAL BASIC STRUCTURE TOTALS ARE IN 7X5 MATRIX AT 50,71
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    SPACE 10
    MPRINT 43,71 SZ 7X5
    SPACE 5
    PERFORM 5.1 THRU 5.2 13 TIMES
    MPRINT MATRIX IN 50,71 SIZE 7X5 (FUNCTIONAL TOTAL VARIANCE MATRIX)
    ASUBTRACT 1,71 SZ 42X1 MINUS 1,72 SZ 42X1 PUT IN 1,79
    ASUBTPACT 1,73 SZ 42X1 MINUS 1,72 SZ 42X1 PUT IN 1,80
    ASUBTRACT 1,75 SZ 42X1 MINUS 1,74 SZ 42X1 PUT IN 1,81
    7/ ASUBTRACT 43.1 SZ 7X1 MINUS 43.2 SZ 7X1 PUT IN 50.1
    8/ ASUBTRACT 43.3 SZ 7X1 MINUS 43.2 SZ 7X1 PUT IN 50.2
    9/ ASUBTRACT 43.5 SZ 7X1 MINUS 43.4 SZ 7X1 PUT IN 50.3
    10/ INCREMENT 7 BY 0 5 0 0 0 5 0 0 0 5
    11/ INCREMENT 8 BY 0 5 0 0 0 5 0 0 0 5
    12/ INCREMENT 9 BY 0 5 0 0 0 5 0 0 0 5
    PERFORM 7 THRU 12 , 13 TIMES
    12.1/ AADD 1,91 SZ 42X1 TO 1,133 PUT IN 1,133
    12.2/INCREMENT 12.1 BY 0 3 0 0 0 0 0 0
    PERFORM 12.1 THRU 12.2 14 TIMES
    12.3/AADD 1,133 SZ 7X1 TO 50,133 PUT IN 50,133
    12.4/INCREMENT 12.3 BY 7 0 0 0 0 0 0 0
    PERFORM 12.3 THRU 12.4 6 TIMES
    29/ MADD MATRIX IN 1,79 SZ 7X3 TO 43,79 SIZE 7X3 PUT IN 43,79
    30/ INCREMENT 29 BY 7 0 0 0 0 0 0 0 0 0
    NEW PAGE
    PERFORM 29 THRU 30 6TIMES
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    NOTE    WBS BASIC STRUCTURE VARIANCES ARE IN 7X3 MATRIX AT 43,79
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    SPACE 3
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    NOTE    FUNCTIONAL BASIC STRUCTURE VARIANCES ARE IN 7X3 AT 50,79
    NOTE    ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    SPACE 5
    MPRINT 43,79 7X3
    31/ MADD MATRIX IN 50,1 SZ 7X3 TO 50,79 SZ 7X3 PUT IN 50,79
    32/ INCREMENT 31 BY 0 5 0 0 0 0 0 0 0 0
```

OMNITAB PROGRAM FOR A-10 COST ACCOUNT VARIANCE REGRESSIONS

LIST OF COMMANDS, DATA AND DIAGNOSTICS

```
      PERFORM 31 THRU 32 13 TIMES
      SPACE 10
      MPRINT 50,79 7X3
      FLEXIBLE
      SPACE 3
      RESET 7
14/   MMOVE MATRIX IN 1,79 SZ 7X3 TO 1,82
15/   SFIT Y IN COL 82, WTS 1.0 TO 1 VAR IN COL 78, COEFF 88, RS 89
16.1/ AMOVE 1,88 SZ 1X1 TO 1,66
16.2/ INCREMENT 16.1 BY 0 0 0 0 0 1
20/   INCREMENT 15 BY 1, 0.0, 0 0 0 0
23/   PERFORM 15 THRU 20, 2 TIMES
23.5/ INCREMENT 16.1 BY 0 0 0 0 1 -3
24/   INCREMENT 15 BY -3, 0.0, 0 0 0 0
27/   INCREMENT 14 BY 7 0 0 0 0 0
      PERFORM 14 THRU 27 , 6 TIMES
14/   MMOVE MATRIX IN 50,1, SZ 7X3 TO 1,82
16.1/ AMOVE 1,88 SZ 1X1 TO 57,1
16.2/ INCREMENT 16.1 BY 0 0 0 0 1 0
23.5/ INCREMENT 16.1 BY 0 0 0 0 -3 1
27/   INCREMENT 14 BY 0 5 0 0 0 0
      PERFORM 14 THRU 27 , 13 TIMES
15/   FIT Y IN COL 82 WTS 1.0 TO 1 VAR IN COL 78, COEFF 88, RES 89
      MMOVE THE MATRIX IN 43,79 SZ 7X3 PUT IN 1,82
16.1/ AMOVE 1,88 SZ 1X1 TO 7,66
16.2/ INCREMENT 16.1 BY 0 0 0 0 0 1
16.3/ DEFINE THE VALUE IN 1,88 INTO COL 90
16.4/ MULTIPLY THE VALUES IN COL 90 78 AND PUT IN COL 90
18/   PAGE PLOT DATA IN COLS 82,90 AGAINST DATA IN COL 78
18.2/ PLOT 82,90,78
18.5/ INCREMENT 18.2 BY 1 0 0
21/   INCREMENT 18 BY 1 0 0
      PERFORM 15 THRU 21 3 TIMES
      AMOVE 43,80 SZ 7X1 TO 1,136 (COST VAR - MAY THRU NOV)
      AMOVE 43,71 SZ 7X1 TO 1,135 (BCWS - MAY THRU NOV)
      DEFINE THE VALUE IN 7,67 INTO COL 85 (TOTAL COST COEFF)
      SET 87 INDEPENDENT VARIABLE MONTHS DEC THRU JUN
      8 9 10 11 12 13 14
      MULTIPLY COL 87 BY COL 85 PUT IN COL 87 (PRED COST VAR)
      AMOVE 1,87 SZ 7X1 TO 8,136 (PRED COST VAR - DEC THRU JUNE )
      AMOVE 50,133 SZ 7X1 TO 8,135 (BCWS MONTHS DECEMBER THRU JUNE)
      SPACE 10
      NOTE  COL 135 = BASIC STRUCTURE BCWS
      NOTE  COL 136 = COST VARIANCE IN ROWS 1-7,PRED COST VAR ROWS 8-14
      SPACE 5
      MPRINT 1,135 SZ 7X2
      SPACE 5
      NOTE  MATRIX OF COEFFICIENTS FOR FUNCTIONAL AREAS
      NOTE  COLS 1-14 = B,E,F,G,N,P,W,Z,Z,6,7,8,C,TOTAL
      NOTE  ROWS 57-59 = SCHEDULE COEFF, COST COEFF, LABOR COEFF
```

OMNITAB PROGRAM FOR A-10 COST ACCOUNT VARIANCE REGRESSIONS

LIST OF COMMANDS, DATA AND DIAGNOSTICS

```
SPACE 5
MPRINT 57,1 SZ 3X14
SPACE 5
NOTE   MATRIX OF COEFFICIENTS FOR WBS ELEMENTS OF BASIC STRUCTURE
NOTE   COLS 66-68 = SCHEDULE COEFF, COST COEFF, LABOR COEFF
NOTE   ROWS 1-7 = 019,049,059,069,079,097,TOTAL
SPACE 5
MPRINT 1,66 SZ 7X3
RESET 7
HEAD 83/EARNED VALUE
MMOVE 43,71 SZ 7X2 TO 1,82
FIT Y IN 83 WTS 1.0 TO 1 VAR IN 82, COEFF 110 , RES IN 111
RESET 14
DEFINE 1,110 INTO 113
AMULT 1,113 SZ 7X1 BY 8,135 PUT IN 8,137 (PRED EARNED VALUE)
AMOVE 43,72 SZ 7X1 TO 1,137 (ACTUAL EARNED VALUE, MAY-NOV)
ADD 137 TO 136 PUT IN 139 (ACTUAL AND PRED ACTUAL COST,EV+COST VAR)
PLOT 135,137,139 VS 78 1.0,14.0,0.0,20000000.0 (BCWS,BCWP,ACWP VS T)
PAGE PLOT 135,137,139,VS 78,1.0,14.0,0.0,20000000.0
PRINT 135,137,139
LIST
STOP
```

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APPENDIX E

Gompertz Regression Program

```
02/28/73    LOGGED IN AT  13.03.52.
            WITH USER-ID GK
            EQUIP/PORT 13/04
COMMAND- EDITOR.
..F,T=,,11,21
..C
  100=2, =NUMBER OF DATA SETS
  110=1, =FIRST DATA SET
  120=5, =NUMBER OF DATA POINTS IN FIRST DATA SET
  130=1.,11., =INDEP VAR AND DEP VAR
  140=2.,21.
  150=3.,28.2
  160=4.,42.1
  170=5.,48.
  180=2, =SECOND DATA SET
  190=4, =NUMBER OF DATA POINTS IN SECOND DATA SET
  200=8.,34.2
  210=2.3,9.1
  220=12.5,55.
  230=21.1,86.2
  240=1, =NUMBER OF EXINT POINTS
  250=15.5
  260==
..171=2,
172=3.5, =NUB_MBER OF EXINT
173=7.
L,A
```

```
100=2           =NUMBER OF DA.A SETS
110=1           =FIRST DATA SET
120=5           =NUMBER OF DATA POINTS IN FIRST DATA SET
130=1.      11.          =INDEP VAR AND DEP VAR
140=2.      21.
150=3.      28.2
160=4.      42.1
170=5.      48.
171=2
172=3.5         =NUMBER OF EXINT
173=7.
180=2           =SECOND DATA SET
190=4           =NUMBER OF DATA POINTS IN SECOND DATA SET
200=8.      34.2
210=2.3     9.1
220=12.5    55.
```

```
   230=21.1        86.2
   240=1             =NUMBER OF EXINT POINTS
   250=15.5
..171=2,=NUMBER OF EXINT POINTS IN FIRST DATA SET
172=3.5, =IND VAR OF EXINT POINT
L,171,172
   171=2             =NUMBER OF EXINT POINTS IN FIRST DATA SET
   172=3.5           =IND VAR OF EXINT POINT
..SAVE,TAPE7
..ATTACH,AA,GROCRV,CY=4
 ATTACH,AA,GROCRV,CY=4.
 CYCLE **, GROCRV
 PFN FOUND IN SD  001
 CYCLE 04, GROCRV
..CONNECT,INPUT,OUTPUT
..RU,F,F=AA
 JOB COMPILING.
      2.724 CP SECONDS COMPILATION TIME

TYPE IN NAME AND EXTENSION
          JOE G JONES EXT 52549
```

PROGRAM TO FIT A GROWTH CURVE TO A SET OF POINTS

FOR DATA SET   1

TYPE "1" IF PEARL IS WANTED, TYPE "0" OTHERWISE 1

TYPE "1" IF GOMPERTZ IS WANTED, "0" OTHERWISE 0

TYPE "1" FOR VON BERTALANFFY, "0" OTHERWISE 1

TYPE "1" FOR HYPERBOLIC TANGENT, "0" OTHERWISE 0

ENTER UPPER LIMIT OF GROWTH CURVE FOR DATA SET (D) 60.

GOMPERTZ CURVE FITTED TO DATA SET 1

BOWS vs. Gomperts Predicted BOWS (I = 125 million)

REGRESSION EQUATION
CONSTANT TERM =   1.46625513
REGRESSION COEFFICIENT =   -.12587365
COEFFICIENT OF DETERMINATION = .00054
CORRELATION COEFFICIENT = -.30016??

Months	Millions of $
INDEP. VAR	FORECAST
1.000000	3.417336
2.000000	5.832507
3.000000	7.613750
4.000000	10.220740
5.000000	14.100044
6.000000	19.257076
7.000000	23.053033
8.000000	28.134558
9.000000	33.561147
10.000000	39.507525
11.000000	44.971873
12.000000	50.751134
13.000000	56.440607
14.000000	62.045400
17.000000	77.312444
20.000000	90.029333
26.000000	107.090574
32.000000	116.234019
35.000000	125.901442
41.000000	128.106513
END GFCCFV	

COMPLETE CURVE FITTED TO DATA SET   1

Predicted Cost Curves for Basic Structures (Est. @ 38 Mo.=46.2, L=46.8)

... :

REGRESSION EQUATION
CONSTANT TERM =   1.76877408
REGRESSION COEFFICIENT =   -.18016080
COEFFICIENT OF DETERMINATION = .00084
CORRELATION COEFFICIENT = -.0007718

Months	$ x 10^3
INLET VAL	FOLLGALT
1.000000	457.708151
2.000000	952.001770
3.000000	1507.615064
4.000000	2245.804107
5.000000	3007.400404
6.000000	5801.007501
7.000000	7601.101004
8.000000	13004.073476
9.000000	10570.117108
10.000000	15276.030913
11.000000	17010.003485
12.000000	20700.171028
13.000000	23360.548004
14.000000	25830.307503
15.000000	27043.503705
18.000000	34216.014211
21.000000	39530.477605
24.000000	41400.203435
27.000000	43431.587070
30.000000	44071.473557
33.000000	45474.655356
36.000000	45973.602704
39.000000	46197.562113
END CROCTV	

..

COMPUTED CURVE FITTED TO DATA SET 1

Predicted Cost Curves for Basic Structures (Est. # 38 Mo.=52.1, L=53.1)

REGRESSION EQUATION
CONSTANT TERM = 1.70901381
REGRESSION COEFFICIENT = -.14319500
COEFFICIENT OF DETERMINATION = .00071
CORRELATION COEFFICIENT = -.30005630

Months	$ x10^3
INLET VAR	FOLLOACT
1.000000	453.047645
2.000000	370.514655
3.000000	1551.438756
4.000000	2532.071000
5.000000	3761.170315
6.000000	5553.377663
7.000000	7504.600155
8.000000	9945.158675
9.000000	12545.248759
10.000000	15303.576233
11.000000	17805.191375
12.000000	21110.056771
13.000000	23602.080677
14.000000	26791.623369
15.000000	29457.217376
18.000000	36433.377660
21.000000	41743.237996
24.000000	45531.131255
27.000000	48120.767593
30.000000	49367.756061
33.000000	51011.032747
36.000000	51755.420105
33.000000	52000.132539
END GECCRV

CONNECT CURVE FITTED TO DATA SET 1

Predicted Cost Curves for Basic Structures (Est. @ 38 Mo.=54.8, L=56.0)

REGRESSION EQUATION
CONSTANT TERM =   1.71516135
REGRESSION COEFFICIENT =   -.14509340
COEFFICIENT OF DETERMINATION = .99985
CORRELATION COEFFICIENT = -.999150

Months	$ x 10^3
INDEP VAR	FORECAST
1.000000	450.500080
2.000000	982.736100
3.000000	1551.427050
4.000000	2595.247730
5.000000	3747.151930
6.000000	5535.237064
7.000000	7570.101070
8.000000	9946.500844
9.000000	12573.362744
10.000000	15437.434443
11.000000	17861.446233
12.000000	21365.456056
13.000000	24354.501677
14.000000	27872.326317
15.000000	30073.926443
18.000000	37403.896403
21.000000	43236.500331
24.000000	47397.894336
27.000000	50293.760474
30.000000	52855.907693
33.000000	53562.652027
36.000000	54423.267945
38.000000	54824.455214

END GFOCRV

COMPLETE CURVE FITTED TO DATA SET   1

Predicted Cost Curves for Basic Structures (Est. $ 38 No.=58.0, L=59.4)

REGRESSION EQUATION
CONSTANT TERM =   1.78503575
REGRESSION COEFFICIENT =   -.14362649
COEFFICIENT OF DETERMINATION = .00065
CORRELATION COEFFICIENT = -.0002860

Months	$ x 10^3
INDEP VAR	FORECAST
1.000000	457.596753
2.000000	777.636104
3.000000	1542.980383
4.000000	2515.893307
5.000000	3940.258319
6.000000	5540.697063
7.000000	7611.303099
8.000000	10020.664353
9.000000	12715.907058
10.000000	15660.727841
11.000000	18637.963495
12.000000	21916.467134
13.000000	24946.475050
14.000000	27919.285084
15.000000	30932.371035
16.000000	33914.436138
21.000000	45126.726672
24.000000	49675.655754
27.000000	52392.107797
30.000000	55095.762409
33.000000	56559.735144
36.000000	57533.599103
39.000000	57993.007765
END GFDCFV	

COMMILTIT CULVE FITTLL TO DATA SET 1

Predicted Cost Curves for Basic Structures (Est. @38 Mo.= 44.2, L=44.75)

REGRESSION ECUATION
CONSTANT TERM = 1.69130319
REGRESSION COEFFICIENT = -.16007957
COEFFICIENT OF DETERMINATION = .02952
CORRELATION COEFFICIENT = -.0907606

Months	$ x 10^3
INDEP VAR	FORECAST
1.000000	433.212111
2.000000	363.710944
3.000000	1556.370067
4.000000	2557.913447
5.000000	3986.091973
6.000000	5602.792145
7.000000	7613.704093
8.000000	9390.301756
9.000000	12374.309420
10.000000	14966.407944
11.000000	17590.723149
12.000000	20204.953712
13.000000	22786.095709
14.000000	25121.097452
15.000000	27361.737609
13.000000	33009.242322
21.000000	37070.425144
24.000000	39329.971312
27.000000	41639.026263
30.000000	42799.076452
33.000000	43532.349215
36.000000	43993.072130
38.000000	44199.162492

END GLOCIV

..

VITAE

Stephen Lynn Amdor was born 9 April 1943, in Mansfield, Illinois. He graduated from Mansfield High School, Mansfield, Illinois, in 1961 and then attended the United States Air Force Academy, Colorado. He was graduated from that institution in June, 1965 with a Bachelor of Science Degree in Engineering Management. Before attending Under-graduate Pilot Training at Williams AFB, Arizona, he was an assistant football coach at the United States Air Force Academy from June 1965 to March 1966. Upon graduation from pilot training, he was assigned to Cannon AFB, N.M., for F-100 combat crew training. Following that, he served a tour of combat in Southeast Asia at Phu Cat AB, Republic of Vietnam. He was then assigned to RAF Lakenheath, England where he performed duties as a member of the 494th Tactical Fighter Squadron and as Wing Standardization/Evaluation Officer for the 48th Tactical Fighter Wing. In July of 1971, he was assigned to Third Air Force Headquarters at South Ruislip AS, England as a Tactical Fighter Staff Officer. In June 1972, he entered the Air Force Institute of Technology as a resident student in Graduate Systems Analysis. He is married to the former Vallerie Grace Petty and has two children; Matthew Todd and Ryan Frederick. His permanent address is:

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Roy Robert Kilgore was born 4 March 1942, in Alamogordo, New Mexico. He graduated from Alamogordo High School, Alamogordo, New Mexico, in 1960. During the 1960-1961 academic year he attended New Mexico State University, University Park, New Mexico and worked on a student cooperative project in San Jose dos Campos, Brazil. He entered the United States Air Force Academy in 1961 and was graduated from there in 1965 with a Bachelor of

Science in Engineering Science Degree. He attended Undergraduate Pilot Training at Laredo AFB, Texas, and was assigned from there to MacDill AFB, Florida for combat crew training as a Pilot Systems Operator. After completing that training, he served a combat tour at Cam Ranh Bay AB, Republic of Vietnam. In April 1968, he was assigned to George AFB, California to upgrade to F-4 Aircraft Commander. From there he was assigned to Homestead AFB, Florida, where he performed duties as an operational F-4 Aircraft Commander, a Replacement Training Unit F-4 Instructor Pilot, and a Wing Academic Instructor for the 31st Tactical Fighter Wing. In August 1972, he entered the Air Force Institute of Technology as a resident student in Graduate Systems Analysis. He is married to the former Corina Ursula Cantu and they have two children: Wendy Ann and Matthew Roy. His permanent address is:

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